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(54) Title: **ULTRA-LOW SHRINKAGE COMPOSITE RESINS BASED ON BLENDED NEMATIC LIQUID CRYSTAL MONOMERS**

(57) Abstract: A novel method of making liquid crystal monomers, novel monomer blends, and novel secondary monomers for use



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**TITLE:       ULTRA-LOW SHRINKAGE COMPOSITE RESINS BASED ON  
              BLENDED NEMATIC LIQUID CRYSTAL MONOMERS**

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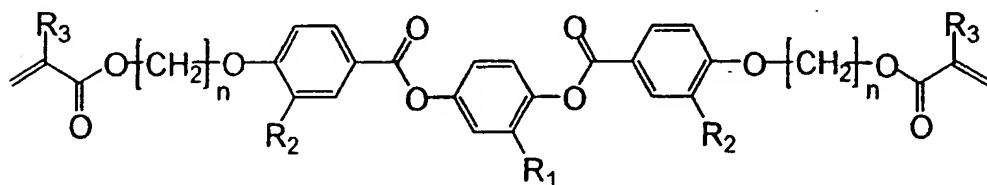
**Background of the Invention**

10       The popularity of dental resin composites as the anterior restorative material  
of choice has continued to grow over recent decades. Resin composites also are  
widely used in posterior applications, particularly in small, lightly loaded restorations.

Dental resin composites have not been universally accepted for use in large  
posterior restorations for a number of reasons, one being cure shrinkage. Volumetric  
15   shrinkage – defined as shrinkage of a curing resin after gelation has occurred – can  
generate interfacial stresses at the resin-tooth junction. These interfacial stresses can  
debond the dentin-restorative interface or fracture the tooth or restorative, which can  
cause marginal leakage, microbial attack, and long term catastrophic failure of the  
bulk restoration.

20       The remarkable advances in dentinal bonding over the past two decades have  
not led to consistent amalgam-like sealing of resin composite restoration margins.  
Instead, the gap has simply moved from the restoration interface to an adjacent area,  
totally within the tooth or totally within the restoration. Even if the interface  
remained intact, shrinkage induced internal stresses may contribute to long-term stress  
25   crack formation and even long-term failure.

Liquid crystal monomers have promise for reducing cure shrinkage and consequent stresses in dental composites. Of greatest interest are the bifunctional terminated, nematic liquid crystal monomers of the type  $C_n(R_2, R_1, R_3)$  shown below:



$R_3 = H \text{ or } CH_3$

Unfortunately, the routes used to date to synthesize these LC monomers are  
 5 complicated, and produce very low yields.

Also, the liquid crystal monomer should maintain a liquid crystalline state during processing in order to be useful in forming dental composites. For comfort in dental applications, the resin should be curable at ambient temperature up to body temperature, or from about 20 °C to about 37 °C. Unfortunately, a resin containing  
 10 only a single bisacrylate terminated, nematic liquid crystal monomer has been found to rapidly crystallize upon addition of filler. It may be possible to alleviate the problem of premature crystallization by blending of monomers; however, certain blends exhibit much higher polymerization shrinkage than others.

Liquid crystal monomers also present a problem because cure shrinkage is  
 15 temperature dependent, and increases rapidly as the  $N \rightarrow I$  transition temperature is approached. If the  $N \rightarrow I$  transition temperature of the LC monomer resin is just slightly above mouth temperature, then excessive polymerization shrinkage may result.

Economic methods are needed for making liquid crystal monomers on a  
 20 commercial scale, and for producing blends of liquid crystal monomers that both

remain in a nematic state under processing conditions and exhibit extremely low cure shrinkage.

### **Summary of the Invention**

A method comprising:

- 5        providing a 4-hydroxyl benzoic acid comprising a carboxyl substituent;  
      providing an alkylene group comprising an  $\alpha$ -hydroxyl group and an  $\omega$ -halide  
          group;  
      condensing said 4-hydroxyl of said benzoic acid with said  $\omega$ -halide group  
          under conditions effective to produce a hydroxyl terminated alkyloxy  
10       comprising said  $\alpha$ -hydroxyl group at a first terminus and said carboxyl  
          substituent of said 4-hydroxyl benzoic acid at a second terminus.

### **Detailed Description of the Invention**

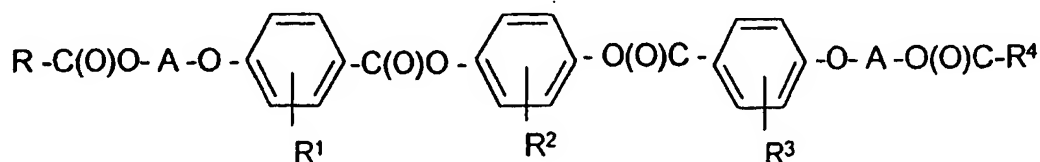
- A relatively simple method of making LC monomers is provided, along with novel monomer blends and novel secondary monomers for use in such blends. The
- 15       blends remain in a nematic state even after the addition of inorganic filler. The blends also exhibit low cure shrinkage. The method is useful to synthesize liquid crystal (LC) monomers with N $\rightarrow$ I temperatures of about 50° C. or more. LC monomers also are blended with related monomers, such as bridged monomers or assymmetric monomers, to produce liquid crystalline blends with nematic stability at from about
- 20       20° C. to about 50° C. The blends resist crystallization for prolonged periods of time, even in the presence of inorganic fillers, while remaining liquid crystalline and exhibiting as low a volumetric shrinkage as possible upon curing. Preferably, the blends remain in the liquid crystalline state for about 10 minutes or more; preferably

30 minutes or more, more preferably about 1 hour or more; even more preferably about 4 hours or more; and, most preferably about 1 month or more. As a practical matter, for dental filling purposes, the filler would be added during manufacture and a shelf life of 6 months or more would be required for commercial acceptability.

- 5            Suitable volumetric shrinkages are about 4 vol.% or less, preferably 2 vol. % or less, more preferably 1.5 vol. % or less.

Liquid crystal monomers have promise for reducing cure shrinkage and consequent stresses in dental composites for several reasons, including but not necessarily limited to improved rheology and "virtual expansion." Oligomeric  
 10            nematics have considerably lower viscosities than isotropic molecules of the same molecular weight because of co-operative reorientation of the molecules under shear. Low viscosity also exists even at high colloidal particle fractions. Conversely, for the same viscosity, a nematic liquid crystal monomer can have a substantially higher molecular weight. This "double bond dilution" results in proportionate reductions in  
 15            polymerization shrinkage. If the structure transforms from nematic to isotropic during polymerization, a further reduction in shrinkage occurs because the more closely packed ordered structure characteristic of the nematic state is lost.

Of greatest interest are the bifunctional terminated, nematic liquid crystal monomers, discussed above. Suitable bifunctional terminated, nematic liquid crystals  
 20            have the following general structure:



wherein:

$R^2$  is a "bulky organic group," defined herein as an organic group having a bulk greater than  $R_1$  and  $R_3$ , said bulk being adapted to provide sufficient steric hindrance to achieve a nematic state at room temperature while suppressing crystallization of the liquid crystal monomers at 20 °C. The result is effective rheology and workability at room temperature. Suitable  $R^2$  groups generate asymmetry in the packing of the molecules, and include, but are not necessarily limited to t-butyl groups, phenyl groups, isopropyl groups, and secondary butyl groups. Most preferred  $R^2$  groups are t-butyl groups; and  $R^1$  and  $R^3$  are selected from groups less bulky than  $R^2$ , preferably selected from the group consisting of hydrogen atoms and methyl groups, preferably hydrogen atoms;

A is selected from the group consisting of branched and linear alkyl groups having from about 2 to about 12 carbon atoms, preferably having from about 2 to about 9 carbon atoms, more preferably having from about 2 to about 6 carbon atoms, and most preferably having about 6 carbon atoms, wherein said branched alkyl groups comprise branches having from about 1 to about 4 carbon atoms; and

R and  $R^4$  are polymerizable groups, including but not necessarily limited to nucleophiles and groups comprising at least one electron deficient alkene. Suitable nucleophiles include, but are not necessarily limited to ester groups, organic acid groups, amine groups, hydroxyl groups, and sulfhydryl groups. More preferred polymerizable groups comprise electron deficient alkenes. Preferred electron deficient alkenes independently are selected from the group consisting of substituted and unsubstituted alkenyl ester groups comprising a

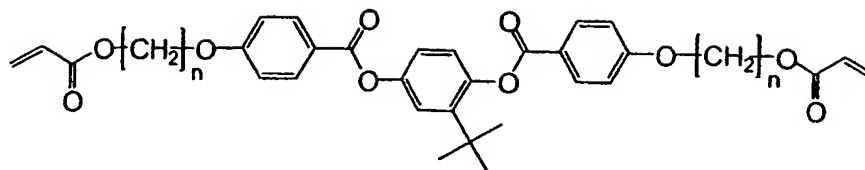


polymerizable unsaturated carbon-carbon bond, wherein said alkenyl group has from about 2 to about 12 carbon atoms.

In a preferred embodiment, R<sup>1</sup> and R<sup>3</sup> are hydrogen, R<sup>2</sup> is a t-butyl group, A is a hexyl group, and R and R<sup>4</sup> are selected from the group consisting of an acryl group  
5 and a methacryl group.

The bisacrylate-terminated liquid crystals can be photopolymerized within seconds with very low polymerization shrinkage to densely crosslinked networks of reaction extent >95% by the usual free radical mechanisms, provided that the polymerization takes place at a high enough temperature. The projected  
10 polymerization shrinkage decreases with lowered polymerization temperature. In fact, the extrapolated room temperature shrinkage of the C6(H,H,H) monomer is approximately 0%.

Preliminary work demonstrated that LC monomers could be synthesized which were nematic over the room to mouth temperature range. Specifically, two  
15 monomers (of the many new monomers synthesized) were shown to exhibit these properties. These monomers were 1,4-bis(4-(6-acryloyl-1-hexyloxy)benzoyloxy)2-t-butylbenzene (the "diacrylate monomer," sometimes called C6-t-butyl-diacrylate, e.g., or simply C6BA). and 1,4-bis(4-(6-methacryloyl-1-hexyloxy)benzoyloxy)2-t-butylbenzene (the "dimethacrylate monomer," sometimes called C6-t-butyl-  
20 dimethacrylate, e.g., or simply C6BMA). The diacrylate monomer has the following general structure, with n being from about 2 to about 12, preferably from about 2 to about 10, more preferably from about 2 to about 6, and most preferably 6:



The mesophase transformation temperatures for certain of these monomers are shown in the following table.

n	Crystalline m.p., °C	S→C*, °C	N→S**, °C	I →N***, °C
6	67	-	15	45
10	72	17	22	43

\*smectic to crystalline transition temperature

\*\*nematic to smectic transition temperature

\*\*\*isotropic to nematic transition temperature

These monomers are metastable nematic at ambient temperatures.

It is true that resins containing a single LC monomer have many advantages.

Single LC monomers are metastable. For example, the "diacrylate monomer" with n = 6 has a nematic (meta)stability range of 15 to 45° C, and a crystalline melting point

of 67° C. After melting and cooling to ambient temperature, a sample of the diacrylate monomer has remained in the nematic liquid crystal state for about 5 years. Liquid crystal (LC) monomers also exhibit much less shrinkage when compared with a conventional reference system, bis-GMA-TEGDMA-Bis-EMA (GTE) (as little as 1.6 percent vs. 8.2 percent, respectively, at similar degrees of conversion). However, it has been discovered that single monomer systems also have the disadvantage of rapidly crystallizing upon addition of filler.

### Novel Method of Synthesis of LC Monomers

The invention provides a novel method for synthesizing a variety of LC monomers, including the bifunctional terminated, nematic monomers discussed

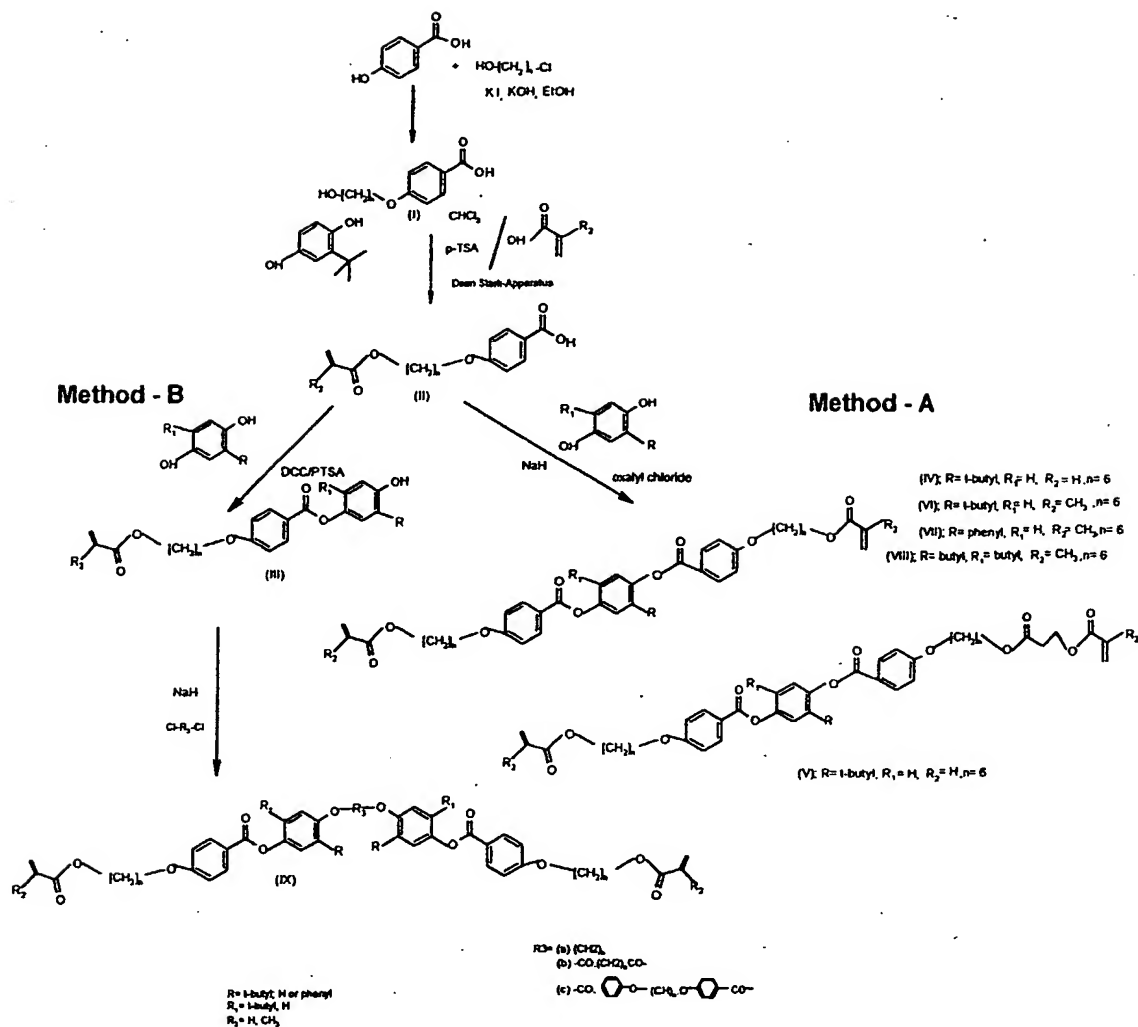


Fig. 2

above. The following is an illustration of the method, generally:

The method involves condensing the 4-hydroxyl group of 4-hydroxyl benzoic

acid with the  $\omega$ -halide group (preferably, an  $\omega$ -chloride) of an  $\alpha$ -hydroxy,  $\omega$ -halo alkane comprising from about 2 to about 12 carbon atoms, producing a corresponding hydroxyl terminated alkyloxy comprising said  $\alpha$ -hydroxyl group at a first terminus and said carboxyl substituent of said 4-hydroxyl benzoic acid at a second terminus.

- 5 The alkane group preferably comprises from about 2 to about 10 carbon atoms, more preferably from about 2 to about 6 carbon atoms, and most preferably 6 carbon atoms. The product yield preferably is about 90% or more.

The 4- $\omega$ -hydroxyalkyloxy benzoic acid is useful as an intermediate for further syntheses. Preferably, the carboxyl substituent of the 4- $\omega$ -hydroxyalkyl benzoic acid  
10 is activated to its acid halide, preferably to its acid chloride using an acid chlorinating agent, such as thionyl chloride, sulfuryl chloride, oxalyl chloride etc., preferably neat oxalyl chloride. The  $\omega$ -hydroxy group is reacted with a polymerizable group under conditions effective to produce an ethereal benzoic acid comprising said polymerizable group at said first terminus and said activated carboxyl group at said  
15 second terminus, in  $\alpha$ - and  $\omega$ - positions. The carboxyl substituent is then reacted with an ionically activated hydroxyl group of a hydroquinone comprising a bulky organic group under conditions effective to produce a compound comprising at least two aromatic rings joined by an ester linkage and comprising a polymerizable group as a first terminus and either a second polymerizable group or the second hydroxyl group  
20 of the hydroquinone as a second terminus.

The bulky organic group of the hydroquinone is adapted to generate asymmetry in packing of the LC monomer and to provide sufficient steric hindrance for the LC monomer to achieve a nematic state at processing conditions while suppressing crystallization of the LC monomer at processing conditions. Processing

conditions comprise a temperature of from about 20 °C. to about 40 °C, preferably from about 20 °C. to about 37 °C. Suitable bulky organic groups include, but are not necessarily limited to t-butyl groups, phenyl groups, isopropyl groups, and secondary butyl groups. In a preferred embodiment, the bulky organic group is a t-butyl group.

5           The polymerizable group is selected from the group consisting of a nucleophile and groups comprising at least one electron deficient alkene. Suitable nucleophiles include, but are not necessarily limited to ester groups, organic acid groups, amine groups, hydroxyl groups, and sulfhydryl groups. More preferred polymerizable groups comprise electron deficient alkenes. Preferred groups  
10   comprising electron deficient alkenes independently are selected from the group consisting of substituted and unsubstituted organic acids comprising a polymerizable unsaturated carbon-carbon bond and comprising from about 2 to about 12 carbon atoms. Most preferred electron deficient alkenes are selected from the group consisting of acrylic acid , and methacrylic acid.

15           In a preferred embodiment, both the first and second hydroxyl groups of said hydroquinone are each reacted with a carboxyl substituent of separate ethereal benzoic acid molecules under conditions effective to produce a nematic liquid crystal comprising three aromatic rings joined by an ester linkage and comprising at least a first polymerizable terminus, preferably both an  $\alpha$  and an  $\omega$  polymerizable termini.

20           While investigating the problems associated with the di-esterification of 2-t-butyl-1,4-hydroquinone with p-( $\omega$ -acryloyloxyhexyloxy)-benzoic acid to produce the MLAP byproduct, the reaction repeatedly produced p-( $\omega$ -acryloxy hexyloxy)-benzoic, 2-t-butyl-1,4-hydroquinone monoester. The most reasonable cause for this monoesterification was the presence of the very bulky tertiary butyl group adjacent to

the 'OH' group on 2-t-butyl hydroquinone monoester derivative. The second esterification reaction was sterically not favored even if a very efficient coupling agent, dicyclohexylcarbodiimide (DCC), was used with the aid of para-toluene sulfonic acid (PTSA) as catalyst and even at elevated temperatures.

5           Without limiting the invention to a particular mechanism, the formation of MLAP as a by-product using acrylic acid is believed to take place via "Michael-type Addition" of a free acrylate group on the double bond of the one propenoyl terminus of 1,4-bis(4-( $\omega$ -acryloyloxy-1-A-oxy)benzoyloxy)2-t-butylbenzene. The presence of an electron donor group next to the 'carbonyl' carbon might reinforce the electron  
10   density on the terminal methylene carbon of the aforesaid propenoyl terminus, and therefore, might discourage the nucleophilic attack by free acrylate anion in the aforesaid Michael-type Addition. As a result, the formation of by-product could be inhibited, leaving behind only 1,4-bis(4-( $\omega$ -methacryloyloxy-1-alkyloxy)benzoyloxy)2-t-butylbenzene as the major product in a clean and a non-  
15   labor intensive reaction. The commercial viability of the synthesis would therefore be increased.

It was, therefore, determined that both 'the carboxyl group' of p-( $\omega$ -acryloxyhexyloxy) benzoic acid and the hydroxyl group of the 2-t-butyl-hydroquinone had to be activated in order to perform a forced coupling between the  
20   two. Hence, p-( $\omega$ -acryloxy hexyloxy)-benzoic acid is activated to its chloride and the 2-t-butyl-hydroquinone is activated to its highly active disodium salt. The coupling between both activated species yields the symmetrical diester of 2-t-butyl-1,4-hydroquinone as a major product.

Where methacrylic acid is used as the "polymerizable group," the method produces a methacryloyl group as a terminus, and the product yield is about 80% or more of 1,4-bis(4-( $\omega$ -methacryloyloxy-1-alkyloxy)benzoyloxy)2-t-butylbenzene.

Where the polymerizable group is acrylic acid, the method produces an acryloyl group as a terminus, and the product yield is about 60% of 1,4-bis(4-( $\omega$ -acryloyloxy-1-alkyloxy)benzoyloxy)2-t-butylbenzene and about 40% of a byproduct having as one terminus an oligomeric ester, namely 2-(t-butyl),1-[4-(6-acryloxy-alkyl-1-oxy)-benzoyloxy], 4-{4-[6-(3-acryloxy-propionyloxy)-alkyl-1-oxy]-benzoyloxy}-benzene.

The method promises versatility for making mono- or even bifunctional terminated, nematic LC monomers at relatively low cost in respectable yields. The method has relatively few reaction steps and does not require purification of intermediates. In addition, the final product may be purified through recrystallization.

The method has been used to synthesize relatively large quantities of the 60/40 diacryl-MLAP product. Single batches of about 100 g of the 60/40 diacryl-MLAP product have been achieved, and the synthesis appears promising for scale up of the manufacture of blends of monomers in commercial quantities.

The invention will be better understood with reference to the following examples, which are illustrative only and not intended as limiting the invention to a particular embodiment.

20

#### EXAMPLE 1

Monomers in which the bulky organic group was a t-butyl group and the alkyl groups were hexyl groups were made as follows. 4-hydroxybenzoic acid was dissolved in 30% ethanolic KOH. About 1% of KI was added as a catalyst. The mixture was heated to about 60 °C and a stoichiometric amount of 6-chloro-1-hexanol

was slowly added over about ½ hour. After refluxing the reaction mixture for extended period of time (2-15 hrs) the contents was cooled, the reaction mixture was filtered off, and the filtrate solvent was evaporated under vacuum. Water was added into the residue and acidified with HCl and the precipitate was filtered and  
5 crystallized with ethanol, yielding approximately an 80% 4-(6- hydroxyhexyloxy)-benzoic acid.

Next, 4-(6- hydroxyhexyloxy benzoic acid was refluxed with a stoichiometric amount of acrylic acid in an excess of cyclohexane as solvent. A catalytic amount of p-TSA was added, along with an appropriate polymerization inhibitor. The flask of  
10 the above contents was fitted with a condenser and Dean Stark trap. When the theoretical amount of water was taken off, the contents were cooled to recover 4-(6- acryloxy-hexyloxy)benzoic acid (II) after a brief work-up.

The chloroform solution containing 4-(6-acryloxy-hexyloxy)benzoic acid (II) was converted to the acid chloride by the slow addition (over about 1 hour) of  
15 stoichiometric amount of an neat oxalyl chloride. After stirring for 4-5 hours, solvent/reagent were distilled off. The di-sodium salt of 2-t-butyl-hydroquinone was prepared by adding stoichiometric NaH to a 10% solution of 2-t-butyl hydroquinone in anhydrous THF (tetrahydrofuran) at room temperature. After hydrogen evolution ceased in the anhydrous THF solution, the acid chloride of 4-(6-acryloxy-  
20 hexyloxy)benzoic acid (II) was slowly added to 2-t-butyl-hydroquinone (di-sodium salt) solution under nitrogen atmosphere. The contents were filtered over chromatographic silica gel to remove the salts and the solvents in filtrate were removed *in vacuo* leaving about 60% of 1,4-bis(4-(6-acryloyl-1-hexyloxy)benzoyloxy)2-t-butylbenzene (IV) and about 40% of a by-product having



one terminus being an oligomeric ester byproduct, namely 2-(t-butyl),1-[4-(6-acryloxy-hexyl-1-oxy)-benzoyloxy], 4-[4-{6-(3-acryloxy-propionoxy)-hexyl-1-oxy}-benzoyloxy]-benzene [(V); "MLAP"].

### EXAMPLE II

5           The methacrylate analog, or 1,4-bis(4-(6-methacryloyloxy-1-hexyloxy)benzoyloxy)2-t-butylbenzene, was synthesized using the method of Example 1 by simply replacing acrylic acid with methacrylic acid. The result was an 80% yield of 1,4-bis(4-(6-methacryloyloxy-hexyl-1-oxy)benzoyloxy)2-(t-butyl) benzene, which remained nematic liquid crystalline between room and mouth  
10   temperatures and could be polymerized to isotropic polymer with about 2% volume shrinkage compared with >8 % for the conventional control (GTE). Unlike the synthesis of its acrylate homolog, the recovery was not split by a sizable amount of MLAP by-product.

### Simplified Method for Forming Key Intermediates

15           The method described above also provides a neat procedure for the mono-esterification of 2-R<sup>3</sup>-1,4-hydroquinone to yield 2-(R<sup>3</sup>)-4-[4-(ω-R-acryloxy-alkyl-1-oxy)-benzoyloxy]-phenol. In a preferred embodiment, 2-t-butyl-1,4-hydroquinone is mono-esterified to get 2-(t-butyl)-4-[4-(6-acryloxy-hexyloxy)-benzoyloxy]-phenol  
(III), which does not need an extensive purification, and is a very versatile  
20   intermediate for the synthesis of other very useful LC monomers.

Another intermediate, p-(ω-acryloxyalkyloxy) benzoic acid (II), preferably p-(ω-hydroxyhexyloxy) benzoic acid, was made using the foregoing reaction and using a very limited amount of solvents, inhibiting the polymerization and adapting a

simpler purification procedure, with a potential for easy scale-up at later stages. The process produced a high yield of about 90% using the foregoing reaction.

Coupling of the monoester, 2-(t-butyl)-4-[4-(6-acryloxy-hexyloxy)-benzoyloxy]-phenol (III in Fig. 2) with (a)  $\alpha,\omega$ -dihaloalkanes or (b)  $\alpha,\omega$ -alkanediacyl halides or (c) alkyloxy- $\alpha,\omega$ -bis-benzoyl halides leads to bridged ethers or esters having the general structures like (IX) in Fig. 2. These structural groups have a potential to exhibit similar polymerization characteristics as that of (IV and VI), and may be useful for blending purposes, as discussed below.

### **Blending of Monomers**

Unfortunately, metastability became a significant problem when attempts were made to formulate filled resin systems. Surprisingly, when silica filler was added to the C6-t-butyl diacrylate monomer, crystallization occurred within a few minutes. The cure shrinkage of unfilled C6-t-butyl diacrylate monomer was temperature dependent, increasing rapidly as the N $\rightarrow$ I transition temperature was approached. With N $\rightarrow$ I transition temperatures just slightly above mouth temperature, monomers such as the C6-ty-butyl diacrylate monomer present a threat of unacceptably high polymerization shrinkage at the desired use temperature.

### **EXAMPLE 3**

Two-tenths of a gram of C6-t-butyl dimethacrylate LC monomer was mixed with 0.8 gram 1.5  $\mu$ m  $\gamma$ -methacryloxy propyltrimethoxy silane treated fused silica to produce an 80% w/w mixture. Mixing was done by hand using an agate mortar and pestle over a period of about 20 minutes. The resultant composite had the consistency and appearance of a commercial dental restorative resin. But, within about 5 minutes

after completion of the mixing, the mixture was found to be solid, the LC monomer crystallized. The resultant material was unworkable, being a frangible solid, even without photoinitiation.

Because of the long-term stability of the monomer in the nematic LC metastable state, even in the presence of potentially nucleating surfaces (i.e., the glass container), this result was unexpected.

In an attempt to solve this crystallization problem, the 60/40 diacryl-MLAP product was substituted for the pure monomer. The working rationale was that the difference in structures between the two constituents would cause each to disrupt the crystalline regularity of the other, thus hindering crystallization.

An 80% w/w blend of the 60/40 diacryl-MLAP product with 1.5  $\mu\text{m}$   $\gamma$ -methacryloxy propyltrimethoxy silane has resisted crystallization at room temperature for over 6 months. Similar results were obtained with two commercial radiopaque glass fillers.

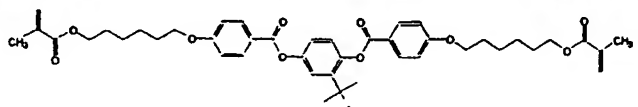
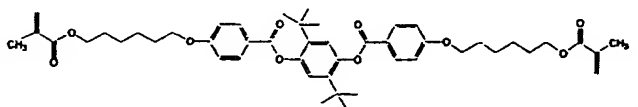
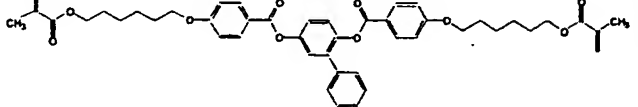
Unfortunately, the 60/40 diacryl-MLAP product exhibited twice the polymerization shrinkage of the original monomer, alone (4.2 vs. 2.0 percent volumetric), and nearly as much as the reference conventional monomer system (GTE, 8.2 percent).

#### **Other Monomers for Forming Blends**

20

An investigation was undertaken to determine new LC analogs suitable for blending with the bifunctional terminated, nematic LC monomers, preferably C6-t-butyl-dimethacrylate monomer, to inhibit polymerization upon addition of filler. The following monomers were synthesized and their volumetric shrinkages (NIST

dilatometer) were measured and compared to the original monomer. The results are given in the following Table:

Monomer Structure	Shorthand Name	Mean Shrinkage, %
	C6-t-butyl-dimethacrylate	2.004
	C6-di-t-butyl-dimethacrylate	Indeterminate (crystalline)
	C6-phenyl-dimethacrylate	1.625

- 5 The di-t-butyl derivative was crystalline at room temperature and the polymerization shrinkage could not be determined for the pure monomer. The phenyl derivative actually had a significantly lower shrinkage ( $p = 0.01$ ) at a similar degree of conversion, 55 vs. 58%. Selected mixtures of these monomers were compared with the reference, GTE, the original C6-t-butyl-dimethacrylate monomer, the original C6-t-butyl-diacrylate monomer, and the spontaneously formed reaction byproduct mixture described earlier, with the following results:

	Monomer(s)	Shrinkage, % vol 150°C (n=4)
Pure Monomers	GTE	8.2
	C6-t-butyl-diacrylate (IV)	2.3
	C6-t-butyl-dimethacrylate (VI)	2.0
	C6-phenyl-dimethacrylate (VII)	1.6
	Acrylate reaction byproduct (V)	7.6
Mixtures	C6-t-butyl-dimethacrylate (VI)+ C6-di-t-butyl-dimethacrylate (3:1)	3.9

	C6-t-butyl-dimethacrylate (VI)+ C6-di-t-butyl-dimethacrylate (1:1)	3.4
	C6-t-butyl-dimethacrylate (VI)+ C6-phenyl-dimethacrylate (VII) (3:1)	2.0
	C6-t-butyl-dimethacrylate (VI)+ C6-phenyl-dimethacrylate (VII) (1:3)	2.1
	C6-t-butyl-diacrylate (VI)+ MLAP (V) (3:2)	4.2 ± 0.2

The pure acrylate and methacrylate LC monomers yielded about one fourth the volumetric shrinkage of the reference monomer system (GTE). Blends with the di-t-butyl derivative yielded shrinkages about twice that of the pure t-butyl monomer. Blends with the phenyl derivative yielded shrinkages equivalent to that of the pure t-butyl monomer. The spontaneously formed di-acrylate blend resulted in a shrinkage approximately twice that of the straight C6-t-butyl-diacrylate monomer. Based on the foregoing data, the phenyl derivative emerged as a preferred diluent or "secondary monomer."

To test the hypothesis that blends of the foregoing monomers would be resistant to crystallization when filled, a variety of formulations were made using a primary monomer, specifically C6-t-butyl-dimethacrylate or C6-t-butyl-diacrylate, blended with a secondary monomer, specifically C6-phenyl-dimethacrylate or the MLAP byproduct, respectively, mixed with either 80% w/w 1.5  $\mu$ m silanized fused silica powder (3M, St. Paul, Minnesota) or 72% w/w small particle size glass filler (Bisco, Schaumburg, Illinois). All monomers were photoinitiated with 1 % w/w camphoroquinone and 0.5% w/w dimethylaminoethyl methacrylate. Mixing was performed using an agate mortar and pestle followed by outgassing for 10 minutes under house vacuum and gentle reconsolidation. None of the tested formulations crystallized over the period monitored (at least one week for all, and over 4 months

for the spontaneous mixture of C6-t-butyl-diacrylate and its reaction byproduct). The resulting shrinkages are shown in the following table.

Monomer	Filler	Shrinkage	Quality*
C6-t-butyl-dimethacrylate (VI)+ C6-phenyl-dimethacrylate (VII) (3:1)	Silica	0.67	+
	Glass	0.49	+
C6-t-butyl-dimethacrylate (VI)+ C6-phenyl-dimethacrylate (VII) (1:3)	Silica	0.89	+
	Glass	-	-
C6-t-butyl-diacrylate (IV)+ MLAP (V) (3:2)	Silica	$0.84 \pm 0.04$	+
	Glass	$1.6 \pm 0.1$	+
	Glass	$1.6 \pm 0.1$	+

5      \*A "+" in the Quality column indicates that the cured product was qualitatively a hard, rigid, translucent resin resembling a commercial dental resin composite. A "-" indicates that the cured specimens were soft and frangible.

All of the foregoing systems resisted crystallization when highly filled. All of the foregoing systems also cured to hard, rigid materials, with the exception of the glass filled butyl-phenyl derivative blend. The glass filler may not be as compatible  
 10      with the LC monomers as with conventional matrix resins. All glass based mixtures had consistencies that differed from those of commercial composites and an experimental 72% w/w filled GTE resin. In contrast, the silica filled resins handled very much like conventional monomer based resin composites. Similar experimental composites made with the pure phenyl derivative monomer did not spontaneously  
 15      crystallize, but also yielded soft, frangible cured resins.

#### Ultra-low shrinkage polymerizable highly filled resin composites

In order to determine the best formulation of ratios and combinations of monomers, when combined with different commercially available fillers, many

composites were formulated and their polymerization shrinkage, hardness, toughness, crystallinity, and other physical properties related to restorative potential evaluated.

The resulting shrinkages (in triplicate) were as follows:

5	25% 2t-bu-dimethacrylate CH <sub>3</sub> -C6LC (VI)—		
	75% 2-ph-dimethacrylate CH <sub>3</sub> -C6LC (VII)	0.710 ±	0.107
	75% 2t-bu-dimethacrylate CH <sub>3</sub> -C6LC (VI) —		
	25% 2-ph-dimethacrylate CH <sub>3</sub> -C6LC (VII)	0.666 ±	0.155
	60% 2t-bu-diacrylate C6LC (IV) —		
10	40% 2t-bu-MLAP- diacrylate C6LC (V)	0.840 ±	0.050
	75% 2t-bu-dimethacrylate CH <sub>3</sub> -C6LC (VI)—		
	25% 2t-bu-MLAP- diacrylate C6LC		
	[(IV)+(V);3:2]	1.183 ±	0.403

15 Additional results are given in Table I.

Table 1. Volume % Shrinkage of New LC-monomers with and without filler				
LC-monomers Type	Volume (%) Shrinkage of monomers with and without filler			
	No filler	silica filler (80%)	Bisco filler (72%)	lab-silica filler(80%)
GTE	8.212	2.483	—	—
2t-bu-Pure diacrylate C6LC (IV)	2.252	—	—	—
2t-bu-Pure By-product of diacrylate C6LC (V)	7.645	—	—	—
2t-bu-Pure dimethacrylate CH <sub>3</sub> -C6LC (VI)	2.004	crystallized	crystallized	—
2-ph-Pure dimethacrylate CH <sub>3</sub> -C6LC (VII)	1.625	—	1.429	—
		—	(Soft)	—
2t-buCH <sub>3</sub> C6LC + 2,5 ditert-CH <sub>3</sub> C6LC(75:25)(VI & VIII)	3.874	—	—	—
2t-buCH <sub>3</sub> C6LC + 2,5 ditert-CH <sub>3</sub> C6LC(50:50)(VI & VIII)	3.414	—	—	—
2t-buCH <sub>3</sub> C6LC + 2-ph-CH <sub>3</sub> C6LC (3:1)(VI & VII)	—	0.666	0.494	—
2t-buCH <sub>3</sub> C6LC + 2-ph-CH <sub>3</sub> C6LC (1:3) (VI & VII)	—	0.893	—	—
			(Soft)	—
2t-bu-Pure diacrylateC6LC + its by-product (3:2)(IV&V)	4.243	0.841	1.352	1.183
Bisco monomer			3.339	

The best properties were shown by a mixture of 2-t-bu-diacrylate and MLAP byproduct at a 3:2 ratio. Therefore, this sample was selected for further testing with various other filler systems (silinated as well as non-silinated) and the data are recorded in Table II. The least polymerization shrinkage of 0.841±0.0404 was exhibited by an 80% wt. loading of silica filler silinated by 3M.

**Table 2. Effect on the Volume% Shrinkage with different Filler System: in C6LC r.m\* (3:2 IV & V) monomers**

Sample No.	filler 0 %	80% silica filler silinated by 3M	Bisco filler 72%	80% silica filler silinated in lab	82% Raysorb T-3000	77% Raysorb Aged
1	4.328	0.839	1.517	1.352	1.415	1.749
2	4.306	0.791	1.595	1.189	1.143	1.502
3	3.841	0.891	1.778	1.386	1.205	1.615
4	4.496		1.504			
Mean	4.2425	0.841	1.5985 ±0.109	1.309	1.2543	1.622
<i>sd</i>	±0.2437	±0.0404	3	±0.086	±0.1164	±0.1010

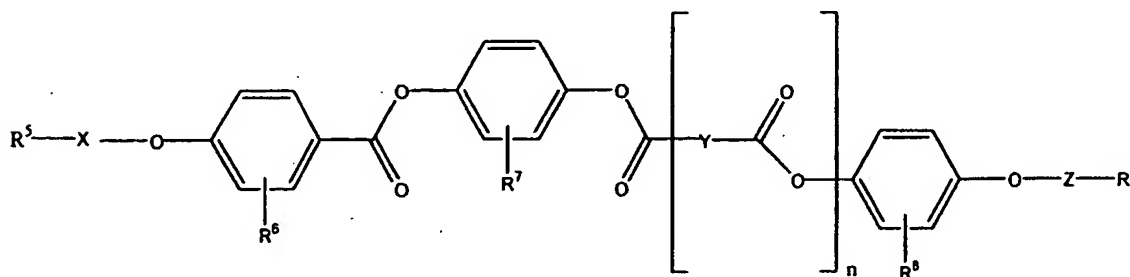
\*"C6LC r.m." is the mixture of Diacrylate liquid crystal monomer and its reaction by-product in a 3:2 ratio



### Use of Secondary Monomer with Higher Transition Temperature

To test the feasibility of using a secondary monomer having a comparatively higher N→I than the primary monomer to raise the N→I transition temperature of the blend, a model system was examined using non-polymerizable LC compounds synthesized as intermediates in the synthesis of new monomers. For example, C6-t-butyl-butyl-dimethacrylate LC monomer was blended with a non-polymerizable C6-t-butyl-dichloro analog. The N→I transition temperature increased linearly with dilution with the higher N→I compound, while the freezing point (not shown) actually was suppressed. This behavior is hereinafter referred to as the “linear rule of mixtures” behavior.

“Bridged monomers” that are suitable for use as secondary monomers having a comparatively higher N→I, have the following general structure:



15

$n$  is selected from the group of 0 and 1;

$X$  is selected from the group consisting of linear and branched alkyl groups having

from about 2 to about 12 carbon atoms, preferably having from about 2 to about 10 carbon atoms, more preferably having from about 2 to about 6 carbon atoms, and most preferably having about 6 carbon atoms;

20

$Y$  is selected from the group consisting linear and branched alkyl groups having from about 2 to about 12 carbon atoms, preferably having from about 2 to about 10

carbon atoms, more preferably having from about 2 to about 6 carbon atoms, and most preferably having about 6 carbon atoms;

Z is selected from the group consisting of alkyl groups and methyl-substituted alkyl groups having from about 2 to about 12 carbon atoms, preferably having from about 2 to about 10 carbon atoms, more preferably having from about 2 to about 6 carbon atoms, and most preferably having about 6 carbon atoms; provided that, when n is 0, Z is further selected from the group consisting of 2-alkyl-1,4-bis[-4-(alkyl-6-yl-1-oxo)-benzoyloxy]-benzene and, when n is 1, Z is further selected from the group consisting of 4-oxoalkyl-benzoyl groups, wherein said alkyls have from about 2 to about 12 carbon atoms, preferably from about 2 to about 10 carbon atoms, more preferably from about 2 to about 6 carbon atoms, and most preferably 6 carbon atoms.

R<sup>7</sup> is a "bulky organic group," defined herein as an organic group having a bulk greater than R<sup>6</sup> and R<sup>8</sup>, said bulk being adapted to provide sufficient steric hindrance to achieve a nematic state at room temperature while suppressing crystallinity of liquid crystal monomers made using the mesogens at room temperature. The result is effective rheology and workability at room temperature. Suitable R<sup>2</sup> groups generate asymmetry in the packing of the molecules, and include, but are not necessarily limited to t-butyl groups, phenyl groups, isopropyl groups, and secondary butyl groups. Most preferred R<sup>2</sup> groups are t-butyl groups and phenyl groups; and

R<sup>6</sup> and R<sup>8</sup> are selected from groups less bulky than R<sup>2</sup>, preferably selected from the group consisting of hydrogen atoms and methyl groups;

R<sup>5</sup> and R<sup>9</sup> are polymerizable groups selected from the group consisting of

nucleophiles and groups comprising at least one electron deficient alkene.

Suitable nucleophiles include, but are not necessarily limited to ester groups, organic acid groups, amine groups, hydroxyl groups, and sulfhydryl groups.

5 More preferred polymerizable groups comprise electron deficient alkenes.

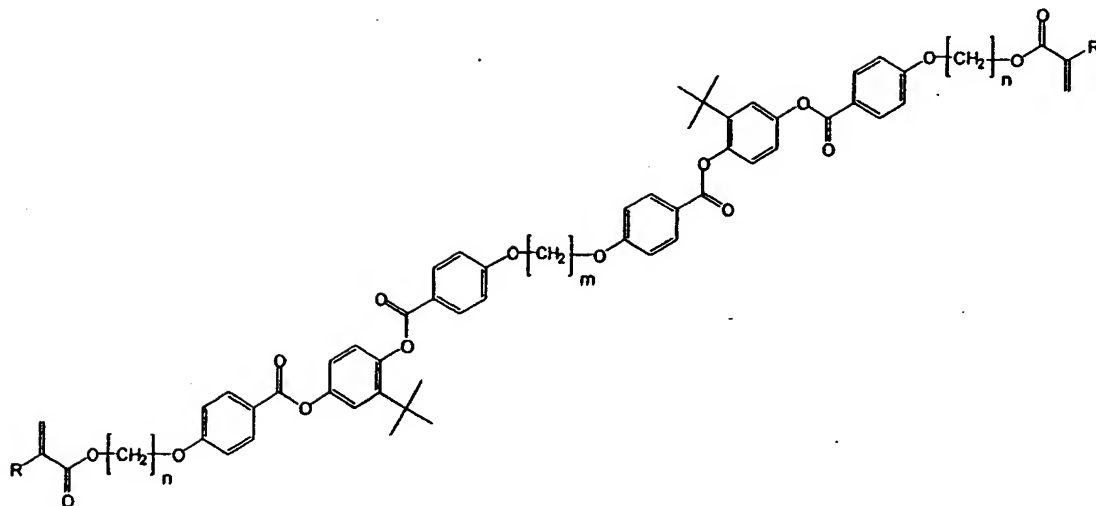
Preferred electron deficient alkenes independently are selected from the group consisting of substituted and unsubstituted alkenyl ester groups comprising a polymerizable unsaturated carbon-carbon bond, wherein said alkenyl group has from about 2 to about 12 carbon atoms.

10 In a preferred embodiment, R<sup>2</sup> is selected from the group of a t-butyl group and a phenyl group, X and Z are hexyl groups, Y is selected from the group consisting of nothing (when n is 0) a hexyl group, and one of R and R<sup>4</sup> is selected from the group consisting of an acryl group and a methacryl group.

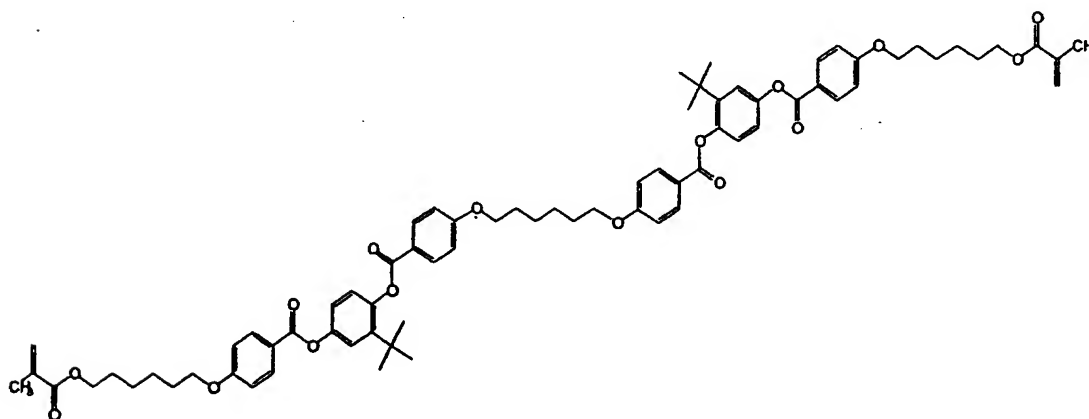
The following are specific examples of suitable bridged monomers that fall  
15 within the foregoing generic structure.

**-Bridged Monomer 1:**

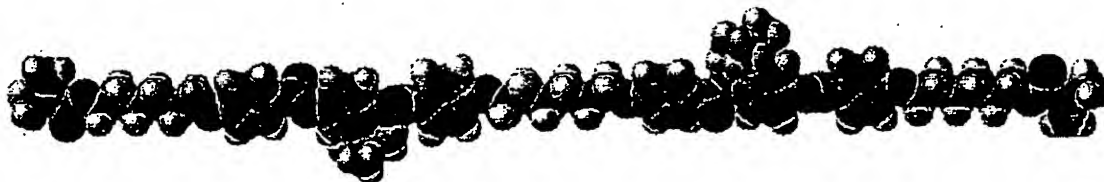
A first bridged monomer is  $\alpha,\omega$ -bis-4-[4-{4-( $\omega$ -R- acryloxy-alkyloxy)-benzoyloxy}-2-R<sup>7</sup>- phenoxy carbonyl]-phenoxy-alkane, preferably  $\alpha,\omega$ -bis-4-[4-{4-( $\omega$ -R acryloxy-alkyloxy)-benzoyloxy}-2-t-butyl phenoxy carbonyl]-phenoxy-alkane:



wherein n and m independently are selected from the group consisting of 2 to 12,  
preferably 2 to 10, more preferably 2 to 6, and most preferably 6, and R is selected  
5 from the group consisting of hydrogen and a methyl group. The “C6-C6-C6 bridged  
dimethacrylate LC monomer”) is shown below:



10 The optimized minimum energy configuration of the C6-C6-C6 bridged  
dimethacrylate LC monomer is shown below. As can be seen, this molecule has the  
rod-like structure characteristic of nematic liquid crystals.

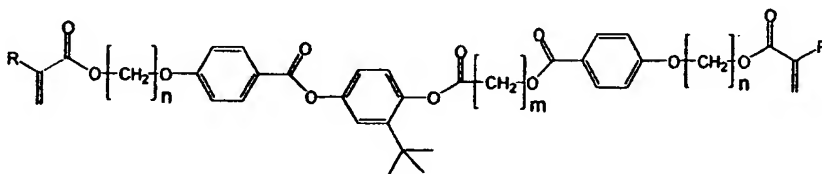


The molecule should have a broad nematic mesophase stability range extending from  
 5 about 20 °C. to about 142 °C.

For the synthesis of this new bridged monomer, a new intermediate, namely alkyl- $\alpha,\omega$ -bis-phenoxy-4-benzoic acid, is synthesized by reacting p-hydroxy benzoic acid with  $\alpha,\omega$ -dihaloalkane, preferably  $\alpha,\omega$ -dichloroalkane, under alkaline conditions and using a suitable condensation catalyst, preferably KI. The carboxyl group of this  
 10 intermediate is then activated to its acid halide, preferably its acid chloride, by refluxing with a suitable carboxylic acid chlorinating agent, such as thionyl chloride, sulfuryl chloride, oxalyl chloride etc., preferably oxalyl chloride. After removal of the reagent/solvent under vacuum, alkyl- $\alpha,\omega$ -bis-phenoxy-4-benzoyl halide, preferably alkyl- $\alpha,\omega$ -bis-phenoxy-4-benzoyl chloride is obtained. The alkyl- $\alpha,\omega$ -bis-phenoxy-4-  
 15 benzoyl chloride is reacted with an ionically activated salt, preferably the sodium salt, of 2-(R<sup>7</sup>)-4-[4-(6-acryloxy-alkyloxy)-benzoyloxy]-phenol, preferably 2-(t-butyl)-4-[4-(6-acryloxy-hexyloxy)-benzoyloxy]-phenol (III in Fig. 2), in anhydrous tetrahydrofuran under nitrogen atmosphere. The contents are filtered over chromatographic silica gel to remove the salts, and the solvents in filtrate are removed  
 20 *in vacuo* leaving  $\alpha,\omega$ -bis-4-[4-{4-( $\omega$ -R acryloxy-alkyloxy)-benzoyloxy}-2-R<sup>7</sup>-phenoxy carbonyl]-phenoxy-alkane, preferably  $\alpha,\omega$ -bis-4-[4-{4-( $\omega$ -R-acryloxy-alkyloxy)-benzoyloxy}-2-t-butyl phenoxy carbonyl]-phenoxy-alkane in good yield.

**-Bridged Monomer 2**

A second suitable bridged monomer is 2-(R<sup>7</sup>)- 1-[4-(ω-R- acryloxy-alkyl-α-oxy)-benzoyloxy], 4-[ω-{4-( ω'-R- acryloxy- alkyl-α-oxy)-benzoyloxy}-α-alkyloxy]-benzene, preferably 2-(t-butyl)- 1-[4-(ω-R-acryloxy-alkyl-α-oxy)-benzoyloxy], 4-[ω-{4-( ω'-R- acryloxy- alkyl-α-oxy)-benzoyloxy}-α-alkyloxy]-benzene:



10

In the foregoing structure, n and m designate the number of carbon atoms in the alkyls, which is from about 2 to about 12, preferably from about 2 to about 10, more preferably from about 2 to about 6, most preferably 6; R is H or CH<sub>3</sub>.

Molecules of this type are made, generally, using two key intermediates described earlier. The sodium salt of 2-(R<sup>7</sup>)-4-[4-(ω-R-acryloxy-alkyloxy)-benzoyloxy]-phenol (III in Fig.2) is treated with an equimolar amount of ω-halo-α-alkanoyl halide, preferably ω-chloro-α-alkanoyl chloride, in THF. After purification, the product is 2-(R<sup>7</sup>)- 1-[4-(ω-R-acryloxy-alkyl-α-oxy)-benzoyloxy], 4-( ω-halo-α-alkanoyloxy)-benzene, preferably 2-(t-butyl)- 1-[4-(ω-R-acryloxy-alkyl-α-oxy)-benzoyloxy], 4-( ω-chloro-α-alkanoyloxy)-benzene. The terminal halo group of this intermediate, preferably a chloro group, is used for esterification of the intermediate 4-(ω-R-acryloxy-alkyloxy) benzoic acids (II in Fig.2), after its conversion to its

20

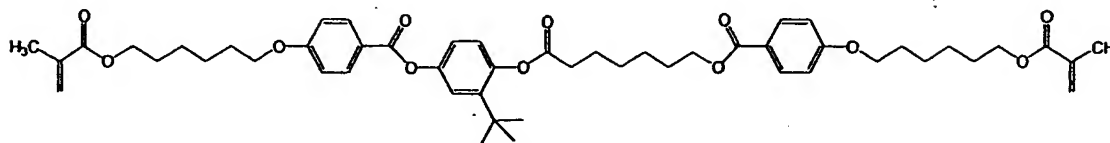
ionically active salt, preferably to its sodium salt by treatment with NaH. The product is 2-(R<sup>7</sup>)- 1-[4-(ω-R-acryloxy-alkyl-α-oxy)-benzoyloxy], 4-[ω-{4-( ω'-R- acryloxy-alkyl-α-oxy)-benzoyloxy}-α-alkyloyloxy]-benzene, preferably 2-(t-butyl)- 1-[4-(ω-R-acryloxy-alkyl-α-oxy)-benzoyloxy], 4-[ω-{4-( ω'-R- acryloxy- alkyl-α-oxy)-benzoyloxy}-α-alkyloyloxy]-benzene.

The detailed synthesis wherein R<sup>7</sup> is a t-butyl group, R is hydrogen, and the alkyl is a hexyl group and is described as follows: The sodium salt of 2-(t-butyl)-4-[4-(6-acryloxy-hexyloxy)-benzoyloxy]-phenol (III in Fig.2) is treated with an equimolar amount of ω-chloro-α-alkanoyl chloride in anhydrous THF under nitrogen atmosphere for 4-5 hours. After purification by filtration over silica gel and the removal of solvents under reduced pressure, the product 2-(t-butyl)- 1-[4-(6-acryloxy-hexyl-α-oxy)-benzoyloxy], 4-( ω-chloro-α-hexanoyloxy)-benzene, is isolated.

An equimolar amount of 4-(6-acryloxy-hexyloxy) benzoic acid (II in Fig.2) is dissolved in anhydrous THF and reacted with sodium hydride (1.1 mol equivalent) for 2 hrs under nitrogen atmosphere at -35 °C. After hydrogen evolution ceases, a THF solution of the equimolar quantity of 2-(t-butyl)- 1-[4-(6-acryloxy-hexyl-α-oxy)-benzoyloxy], 4-( ω-chloro-α-hexanoyloxy)-benzene is introduced into the reaction vessel slowly. The reaction mixture is stirred at room temperature for 4-5 hours. The contents are filtered over chromatographic silica gel to remove the salts and the solvents in filtrate are removed *in vacuo* leaving a respectable yield of 2-(t-butyl)- 1-[4-(6- acryloxy-hexyl-α-oxy)-benzoyloxy], 4-[6-{4-( 6'-acryloxy- hexyl-α-oxy)-benzoyloxy}-α-hexyloyloxy]-benzene.

Where n = m = 6, the structure essentially is the C6BM monomer with an

additional  $(\text{CH}_2)_6\text{COO}$  spacer group bridging adjacent phenyl groups:



The minimum energy configuration of the foregoing molecule is shown below:

5

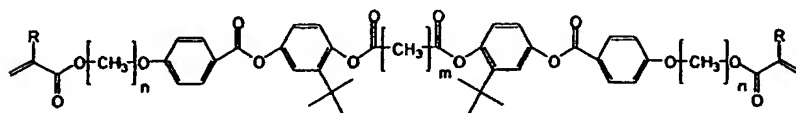


Figure 6. Asymmetrical Bridged Monomer

### 10 Bridged Monomer 3

A third suitable bridged monomer is nonanedioic acid- $\alpha,\omega$ -bis-(2- $\text{R}^7$ )-4-[4-{ $\omega$ -(2- $\text{R}$ -acryloyloxy)-alkyloxy}-benzoyloxy]-phenyl ester, wherein the alkyl groups comprise from about 2 to about 12 carbon atoms, preferably 2 to about 10 carbon atoms, more preferably from about 2 to about 6 carbon atoms, most preferably 6 carbon atoms. This molecule has the following general structure:

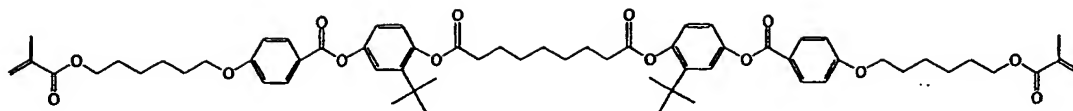
15



A preferred third bridged monomer, nonanedioic acid- $\alpha,\omega$ -bis-(2-*t*-butyl)-4-[4-{6-(2-methyl-acryloyloxy)-hexyloxy}-benzoyloxy]-phenyl ester, has the following general structure:

20





The minimal energy conformation of this molecule is shown below:



For the synthesis of these new monomers, a new intermediate, namely alkyl- $\alpha,\omega$ -bis-phenoxy-4-benzoic acid is synthesized by reacting p-hydroxy benzoic acid with  $\alpha,\omega$ -dihaloalkane, preferably  $\alpha,\omega$ -dichloroalkane, in alkaline conditions and catalyzed by a suitable condensation catalyst, preferably KI. The carboxyl group of this intermediate is then activated to its halide, preferably to its chloride, by refluxing with an appropriate acid halogenating agent, preferably an acid chlorinating agent, such as thionyl chloride, sulfuryl chloride, oxalyl chloride etc. A most preferred acid chlorinating agent is oxalyl chloride. After removal of the reagent/solvent under vacuum, alkyl- $\alpha,\omega$ -bis-phenoxy-4-benzoyl chloride is obtained, which is reacted with the sodium salt of 2-(R<sup>7</sup>)-4-[4-(6-acryloxy-alkyloxy)-benzoyloxy]-phenol, preferably 2-(t-butyl)-4-[4-(6-acryloxy-hexyloxy)-benzoyloxy]-phenol (III in Fig.2) in anhydrous tetrahydrofuran under nitrogen atmosphere.

The specific synthesis of nonandioic- $\alpha,\omega$ -bis-(2-t-butyl)-4-[4-{6-(2-methyl-acryloyloxy)-hexyloxy}-benzoyloxy]-phenyl ester is outlined below:

Nonanedioic acid is treated with an excess of neat oxalyl chloride at room

temperature for 2-3 hours. The excess of oxalyl chloride is removed in-vacuo to get sufficiently pure nonanedioic acid chloride. In a separate vessel, 2-(t-butyl)-4-[4-(6-acryloxy-hexyloxy)-benzoyloxy]-phenol (III in Fig. 2) is reacted with sodium hydride (1.1 molar equivalent) in anhydrous tetrahydrofuran under nitrogen atmosphere at –  
5 35°C. After the evolution of hydrogen ceases, an equimolar amount of nonanedioic acid chloride in anhydrous THF is added to this reaction vessel slowly under nitrogen atmosphere at –35 °C. After all of the nonanedioic acid chloride is added, the reaction is allowed to stir at room temperature for 4-5 hours. The contents are filtered over chromatographic silica gel to remove the salts and the solvents in filtrate are removed  
10 *in vacuo* leaving nonanedioic- $\alpha,\omega$ -bis-(2-t-butyl)-4-[4-{6-(2-methyl-acryloyloxy)-hexyloxy}-benzoyloxy]-phenyl ester in good yield.

#### Testing of Filled Products

Blends of the foregoing bridged monomers with C6BM are made using the linear rule of mixtures behavior to achieve a nematic to isotropic transition  
15 temperature of about 50 ° C. or more, preferably 60° C. or more. The mixtures are tested to determine cure shrinkage neat and filled with 80% w/w small particle glass filler, and to verify that the mixtures do not crystallize at controlled room temperature, or 20° C. Accelerated crystallization resistance testing is also performed at 4° C for those mixtures with freezing points above that temperature.

20 Suitable blends meet the following criteria: nematic to crystallization temperature ( $T_{N \rightarrow Cr}$ ) of about 20° C. or lower;  $T_{N \rightarrow I}$  of about 40 °C. or higher, preferably about 45 °C. to about 70 °C., although any higher limit is acceptable provided that it is not accompanied by a viscosity which makes the material unusable for the intended purpose, a preferred purpose being for dental restorative purposes;

change in volume at curing ( $\Delta V_{\text{curing}}$ ) of about 4% or less (neat);  $\Delta V_{\text{curing}}$  of about 1% or less (filled); no crystallization at 20° C for about 6 months or more, preferably about 12 months or more, more preferably about 2 years or more, most preferably 4 years or more (filled). For filled systems that do not freeze above 4° C, no

5 crystallization at 4° C for about 2 months or more (filled) will be substituted for the last criterion. More preferred blends will meet the following criteria:  $T_{N \rightarrow Cr} > 10^\circ \text{C}$ ;  $T_{N \rightarrow I} > 60^\circ \text{C}$ ;  $\Delta V_{\text{curing}} < 4\%$  (neat);  $\Delta V_{\text{curing}} < 1\%$  (filled); no crystallization at 20° C for 6 months or more (filled). For filled systems that do not freeze above 4° C., no

10 crystallization at 4° C for 2 months or more (filled) will be substituted for the last criterion.

The fracture toughness of cured blends is tested using defined crack compact tensile samples (ASTM E399) fabricated by photocuring C6BM monomer with initiator and activator in silicone molds. After surfacing samples with 600 grit SiC paper and soaking in physiologic saline at 37° C. for 24 hours, the samples are tested

15 at room temperature under displacement control at 1mm/min until failure. The C6BM monomer synthesized in this study yielded a cross-linked polymer with a somewhat lower cross-link density at the same degree of conversion when compared with the GTE reference system, because of the LC monomer's higher molecular weight. Not surprisingly, the fracture toughness of the crosslinked, glassy C6BM is  $0.5 \text{ MPa}\cdot\text{m}^2$  --

20 which is identical to that found for the photocured, isotropic conventional matrix resin GTE. The fracture toughness of the crosslinked, cured resin blend is as high as possible, suitably  $0.4 \text{ MPa}\cdot\text{m}^{1/2}$  or higher, preferably  $0.5 \text{ MPa}\cdot\text{m}^{1/2}$  or higher.

Persons of ordinary skill in the art will recognize that many modifications may be made to the present invention without departing from the spirit and scope of the

present invention. The embodiment described herein is meant to be illustrative only and should not be taken as limiting the invention, which is defined in the following claims.

**We claim:**

1           1.     A method comprising:  
2     providing a 4-hydroxyl benzoic acid comprising a carboxyl substituent;  
3     providing an alkylene group comprising an  $\alpha$ -hydroxyl group and an  $\omega$ -halide group;  
4     condensing said 4-hydroxyl of said benzoic acid with said  $\omega$ -halide group under  
5     conditions effective to produce a hydroxyl terminated alkyloxy comprising said  $\alpha$ -  
6     hydroxyl group at a first terminus and said carboxyl substituent of said 4-hydroxyl  
7     benzoic acid at a second terminus.

1           2.     A method comprising:  
2     providing a 4-hydroxyl benzoic acid comprising a carboxyl substituent;  
3                 providing an alkylene group comprising an  $\alpha$ -hydroxyl group and an  
4                  $\omega$ -halide group;  
5     condensing said 4-hydroxyl of said benzoic acid with said  $\omega$ -halide group  
6                 under conditions effective to activate said carboxyl group and to  
7                 produce a hydroxyl terminated alkyloxy comprising said  $\alpha$ - hydroxyl  
8                 group at a first terminus and an activated carboxyl substituent of said  
9                 4-hydroxyl benzoic acid at a second terminus;  
10    reacting a polymerizable group with said first terminus under conditions  
11                 effective to produce an ethereal benzoic acid comprising said activated  
12                 carboxyl substituent in a position para- to a polymerizable terminus;  
13                 and,  
14                 providing a hydroquinone comprising a bulky organic group and  
15                 comprising a first hydroxyl group para- to a second hydroxyl group, at

16           least one of said first hydroxyl group and said second hydroxyl group  
17           being an ionically activated hydroxyl group;  
18       condensing said at least one ionically activated hydroxyl group of said  
19           hydroquinone with said activated carboxyl substituent of said ethereal  
20           benzoic acid under conditions effective to produce a compound  
21           comprising at least two aromatic rings joined by an ester linkage and  
22           comprising a polymerizable terminus and a terminus selected from the  
23           group consisting of a second polymerizable terminus and said second  
24           hydroxyl group of said hydroquinone.

1       3.    A method comprising:  
2       providing a 4-hydroxy benzoic acid comprising a carboxyl substituent;  
3           providing an alkylene group comprising an  $\alpha$ -hydroxyl group and an  
4            $\omega$ -halide group;  
5       condensing said 4-hydroxyl substituent of said benzoic acid with said  $\omega$ -halide  
6           group under conditions effective to produce a hydroxyl terminated  
7           alkyloxy comprising said  $\alpha$ -hydroxyl group of said alkylene group at a  
8           first terminus and said carboxyl substituent of said benzoic acid at a  
9           second terminus;  
10      reacting a polymerizable group with said first terminus under conditions  
11           effective to produce an ethereal benzoic acid comprising said activated  
12           carboxyl substituent in a position para- to a polymerizable terminus;  
13      and,  
14      providing a hydroquinone comprising a bulky organic group and  
15      comprising a first hydroxyl group para- to a second hydroxyl group, at

16           least one of said first hydroxyl group and said second hydroxyl group  
17           being an ionically activated hydroxyl group;  
18       condensing said at least one ionically activated hydroxyl group of said  
19           hydroquinone with said activated carboxyl substituent of said ethereal  
20           benzoic acid under conditions effective to produce a nematic liquid  
21           crystal comprising three aromatic rings joined by an ester linkage and  
22           comprising at least a first polymerizable terminus.

1           4.     The method of any of claims 1-3 wherein said  $\omega$ -halide group is a  $\omega$ -  
2     chlorine group.

1           5.     The method of any of claims 1-4 wherein said alkylene group  
2     comprises from about 2 to about 12 carbon atoms.

1           6.     The method of any of claims 1-4 wherein said alkylene group  
2     comprises from about 2 to about 10 carbon atoms.

1           7.     The method of any of claims 1-5 wherein said polymerizable group is  
2     selected from the group consisting of a nucleophile and groups comprising at least  
3     one electron deficient alkene.

1           8.     The method of any of claims 1-5 wherein said polymerizable group is  
2     selected from the group consisting of ester groups, organic acid groups, amine groups,  
3     hydroxyl groups, and sulfhydryl groups.

1           9.     The method of any of claims 1-5 wherein said polymerizable group is  
2     an electron deficient alkene independently selected from the group consisting of  
3     substituted and unsubstituted alkenyl ester groups comprising a polymerizable  
4     unsaturated carbon-carbon bond, wherein said alkenyl group has from about 2 to  
5     about 12 carbon atoms.

1           10.    The method of any of claims 1-5 wherein said polymerizable group is  
2    an electron deficient alkene selected from the group consisting of alkenyl esters,  
3    acryloyl groups, methacryloyl groups.

1           11.    The method of any of claims 1-5 wherein said bulky organic group is  
2    adapted to generate asymmetry in packing of said nematic liquid crystal monomer and  
3    to provide sufficient steric hindrance for said nematic liquid crystal monomer to  
4    achieve a nematic state at processing conditions while suppressing crystallization of  
5    said nematic liquid crystal monomer at processing conditions.

1           12.    The method of any of claims 1-11 wherein said processing conditions  
2    comprise a temperature of from about 20 °C. to about 40 °C.

1           13.    The method of any of claims 1-12 wherein said bulky organic group is  
2    selected from the group consisting of t-butyl groups, phenyl groups, isopropyl groups,  
3    and secondary butyl groups.

1           14.    The method of any of claims 1-12 wherein said bulky organic group is  
2    at-butyl group.

1           15.    The method of any of claims 1-14 producing a yield of said nematic  
2    liquid crystal of about 50% or more.

1           16.    The method of any of claims 1-15 producing a yield of said ethereal  
2    benzoic acid of about 90% or more.

1           17.    The method of any of claims 1-16 wherein said polymerizable group is  
2    a methacryloyl group, and said method has a product yield of said nematic liquid  
3    crystal about 80% or more.

1           18.    A resin blend comprising inorganic filler and a primary liquid crystal  
2    monomer at a ratio to a secondary monomer, said secondary monomer and said ratio



3 being adapted to maintain said resin blend in a nematic liquid crystalline state for  
 4 about 30 minutes or more after addition of an inorganic filler at a temperature of 20  
 5 °C.

1 19. The resin blend of claim 18 wherein said blend exhibits about 4 vol.%  
 2 or less polymerization shrinkage.

1 20. The resin blend of claim 18 wherein said blend exhibits about 2 vol.%  
 2 or less polymerization shrinkage.

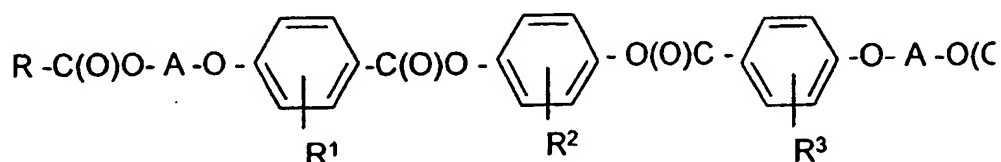
1 21. The resin blend of claim 18 wherein said blend exhibits about 1.5  
 2 vol.% or less polymerization shrinkage.

1 22. The resin blend of any of claims 18-21 wherein said resin blend  
 2 maintains said nematic liquid crystalline state for about 1 hour or more.

1 23. The resin blend of any of claims 18-21 wherein said resin blend  
 2 maintains said nematic liquid crystalline state for about 4 hours or more.

1 24. The resin blend of any of claims 18-21 wherein said resin blend  
 2 maintains said nematic liquid crystalline state for about 6 months or more.

1 25. The resin blend of any of claims 18-24 wherein said liquid crystal  
 2 monomer has the following general structure:



3  
 4 wherein:

5  $R^2$  is a bulky organic group having a bulk greater than  $R_1$  and  $R_3$ , said bulk  
 6 being adapted to provide sufficient steric hindrance for said liquid  
 7 crystal monomer to achieve a nematic state at room temperature while

- 8 suppressing crystallization of said liquid crystal monomers at 20°C;  
9 R<sup>1</sup> and R<sup>3</sup> are selected from the group consisting of hydrogen atoms  
10 and methyl groups;  
11 A is selected from the group consisting of branched and linear alkyl groups  
12 having from about 2 to about 12 carbon atoms, wherein said branched  
13 alkyl groups comprise branches having from about 1 to about 4 carbon  
14 atoms; and  
15 R and R<sup>4</sup> are polymerizable groups, including but not necessarily limited to  
16 nucleophiles and electron deficient alkenes.
- 1 26. The resin blend of any of claims 18-25 wherein R<sup>2</sup> is selected from the  
2 group consisting of t-butyl groups, phenyl groups, isopropyl groups, and secondary  
3 butyl groups.
- 1 27. The resin blend of any of claims 18-25 wherein R<sup>2</sup> is a t-butyl group.
- 1 28. The resin blend of any of claims 18-27 wherein A comprises from  
2 about 2 to about 10 carbon atoms.
- 1 29. The resin blend of any of claims 18-27 wherein A comprises from  
2 about 2 to about 6 carbon atoms.
- 1 30. The resin blend of any of claims 18-27 wherein A has 6 carbon atoms.
- 1 31. The resin blend of claim any of claims 18-30 wherein said  
2 polymerizable groups are nucleophiles selected from the group consisting of ester  
3 groups, organic acid groups, amine groups, hydroxyl groups, and sulfhydryl groups.
- 1 32. The resin blend of any of claims 18-30 wherein said polymerizable  
2 groups comprise electron deficient alkenes.

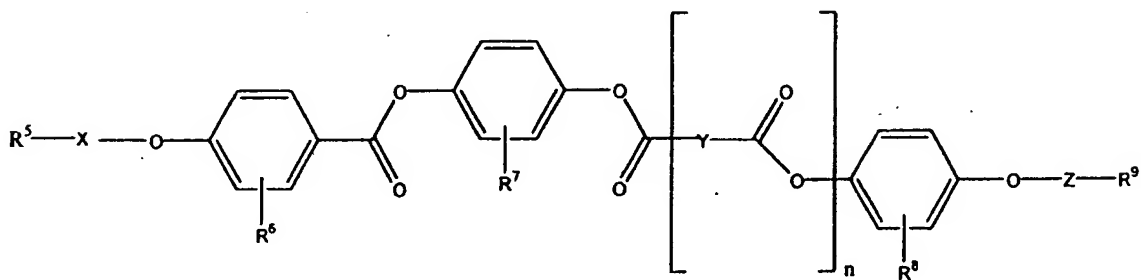
1           33.    The resin blend of claim 32 wherein said electron deficient alkenes  
2   independently are selected from the group consisting of substituted and unsubstituted  
3   alkenyl ester groups comprising a polymerizable unsaturated carbon-carbon bond,  
4   wherein said alkenyl group has from about 2 to about 12 carbon atoms.

1           34.    The resin blend of claim 32 wherein said polymerizable groups are  
2   acryloyl groups and methacryloyl groups.

1           35.    The resin blend of any of claims 18-34 wherein said secondary  
2   monomer is 2-(t-butyl),1-[4-(6-acryloxy-hexyl-1-oxy)-benzoyloxy], 4-[4-{6-(3-acryl  
3   oxy-propionoxy)-hexyl-1-oxy}-benzoyloxy]-benzene.

1           36.    The resin blend of any of claims 18-34 wherein said secondary  
2   monomer is 2-(t-butyl),1-[4-(6-acryloxy-hexyl-1-oxy)-benzoyloxy], 4-[4-{6-(3-acryl  
3   oxy-propionoxy)-hexyl-1-oxy}-benzoyloxy]-benzene.

1           37.    The resin blend of any of claims 18-34 wherein said secondary  
2   monomer has the following general structure:



3

4

5   wherein

6           n is selected from the group of 0 and 1;

7           X and Y independently are selected from the group consisting of linear and

8           branched alkyl groups having from about 2 to about 12 carbon atoms;

9           Z is selected from the group consisting of linear and branched alkyl groups  
10           having from about 2 to about 12 carbon atoms; provided that, when n  
11           is 0, Z is further selected from the group consisting of 2-alkyl-1,4-bis[-  
12           4-(alkyl-6-yl-1-oxo)-benzoyloxy]-benzene and, when n is 1, Z is  
13           further selected from the group consisting of 4-oxoalkyl-benzoyl  
14           groups, wherein said alkyl groups independently have from about 2 to  
15           about 12 carbon atoms;

16           R<sup>7</sup> is a bulky organic group having a bulk greater than R<sub>1</sub> and R<sub>3</sub>, said bulk  
17           being adapted to provide sufficient steric hindrance for said liquid  
18           crystal monomer to achieve a nematic state at room temperature while  
19           suppressing crystallization of said blend at 20 °C;

20           R<sup>6</sup> and R<sup>8</sup> are selected from the group consisting of hydrogen atoms and  
21           methyl groups;

22           R<sup>5</sup> and R<sup>9</sup> are secondary polymerizable groups selected from the group  
23           consisting of nucleophiles and groups comprising an electron deficient  
24           alkene.

1           38.    The resin blend of any of claims 18-34 wherein said secondary  
2           monomer is  $\alpha,\omega$ -bis-4-[4-{4-( $\omega$ -R-acryloxy-alkyloxy)-benzoyloxy}-2-R<sup>7</sup>-phenoxy  
3           carbonyl]-phenoxy-R<sup>13</sup> wherein:

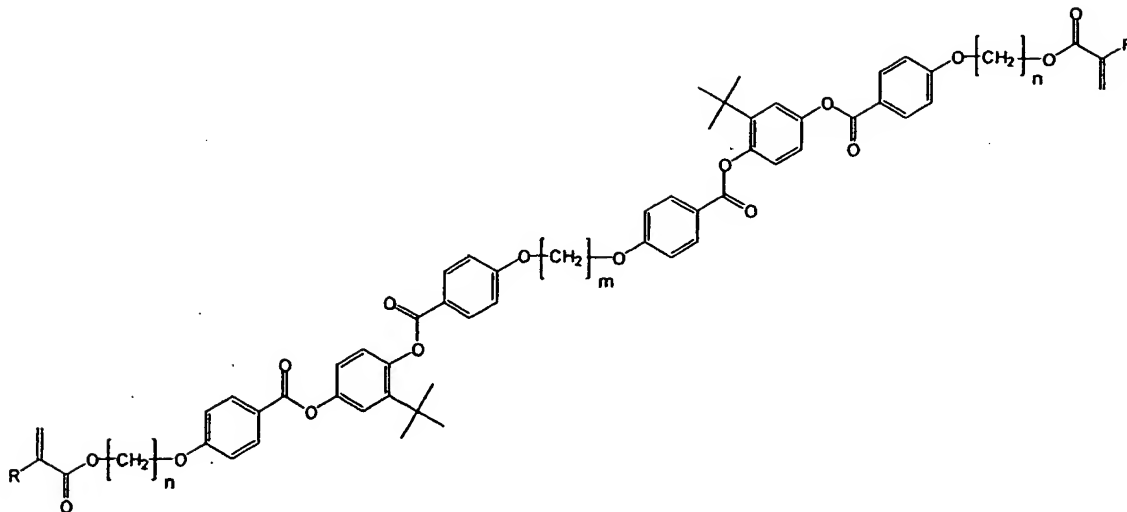
4           said alkyls have from about 2 to about 12 carbon atoms; and

5           R is selected from the group consisting of H and CH<sub>3</sub>;

6           R<sup>7</sup> independently is selected from the group consisting of t-butyl groups,  
7           phenyl groups, isopropyl groups, and secondary butyl groups;

8           and R<sup>13</sup> is selected from the group consisting of hydrogen and a methyl group.

- 1            39.    The resin blend of any of claims 18-34 wherein said secondary  
2    monomer has the following general structure:

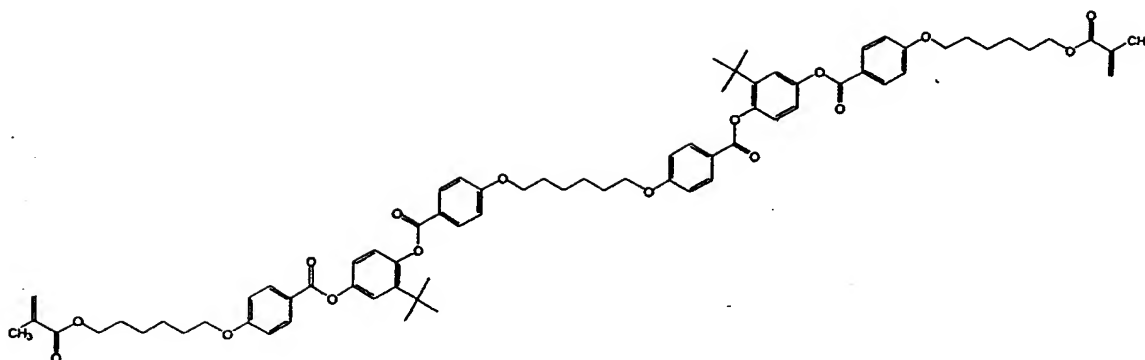


3    wherein

- 4            R is selected from the group consisting of hydrogen and a methyl group; and  
5            n and m independently are selected from the group consisting of from about 2  
6            to about 12.

- 1            40.    The resin blend of claim 47 wherein n and m are selected from the  
2    group consisting of from about 4 to about 11.

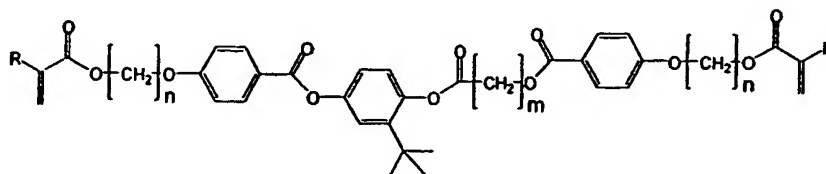
- 1            41.    The resin blend of any of claims 18-34 wherein said secondary  
2    monomer is a composition having the following general structure:



1           42.     The resin blend of any of claims 18-34 wherein said secondary  
2     monomer is n-[4-({n-[(2-(R<sup>7</sup>)-4-{4-[n-(2-R-prop-2-nyloxy)alkyloxy]phenylcarbonyl  
3     oxy}phenyl)oxycarbonyl]alkyl} oxycarbonyl)phenoxy]alkyl 2-R-prop-2-enoate  
4     wherein:

5 R is selected from the group consisting of hydrogen and a methyl group; and  
6 said alkyls have from about 2 to about 12 carbon atoms; and  
7 R<sup>7</sup> is selected from the group consisting of a t-butyl group, a phenyl group, an  
8 isopropyl group, and a secondary butyl group.

1            43.    The resin blend of any of claims 18-34 wherein said secondary  
2    monomer has the following general structure:

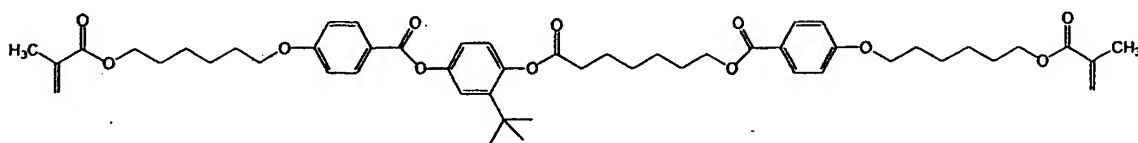


3 wherein

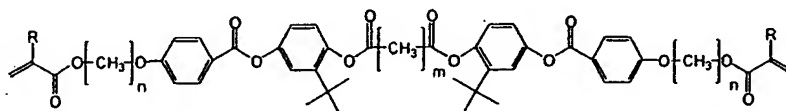
4 n and m independently are selected from the group consisting of from about 2  
5 to about 12; and

6 R is selected from the group consisting of H and CH<sub>3</sub>.

- 1           44.    The resin blend of any of claims 18-34 wherein said secondary  
2 monomer has the following general structure:



- 1           45.    The resin blend of any of claims 18-34 wherein said secondary  
2 monomer has the following general structure:



3           wherein

4           n and m independently are selected from the group consisting of from about 2  
5           to about 12; and

6           R is selected from the group consisting of H and CH<sub>3</sub>.

- 1           46.    The resin blend of any of claims 18-34 wherein said secondary  
2 monomer is nonanedioic acid- $\alpha,\omega$ -bis-(2-R<sup>7</sup>)-4-[4-{6-(2-R-acryloyloxy)-alkyloxy}-  
3 benzoyloxy]-phenyl ester wherein:

4           said alkyl has from about 2 to about 12 carbon atoms; and

5           R<sup>7</sup> is selected from the group consisting of a t-butyl group, a phenyl group, an  
6 isopropyl group, and a secondary butyl groups; and

7           R is selected from the group consisting of H and CH<sub>3</sub>.

- 1           47.    The resin blend of any of claims 35-46 wherein R<sup>7</sup> is selected from the  
2 group consisting of t-butyl groups, phenyl groups, isopropyl groups, and secondary  
3 butyl groups.

1           48.    The resin blend of any of claims 35-46 wherein R<sup>7</sup> is selected from the  
2   group consisting of a t-butyl group and a phenyl group.

1           49.    The resin blend of any of claims 35-46 wherein R<sup>7</sup> is a t-butyl group.

1           50.    The resin blend of any of claims 35-46 wherein n and m  
2   independently are from about 2 to about 10, and said alkyl(s) of said secondary  
3   monomer independently have from about 2 to about 10 carbon atoms.

1           51.    The resin blend of any of claims 35-46 wherein said alkyl(s) of said  
2   secondary monomer independently have from about 2 to about 6 carbon atoms.

1           52.    The resin blend of any of claims 35-46 wherein said alkyl(s) of said  
2   secondary monomer have 6 carbon atoms.

1           53.    The resin blend of any of claims 35-46 wherein both of said R<sup>5</sup> and R<sup>9</sup>  
2   are secondary polymerizable groups.

1           54.    The resin blend of any of claims 35-53 wherein said secondary  
2   polymerizable groups are nucleophiles selected from the group consisting of an ester  
3   group, an organic acid group, an amine group, a hydroxyl group, and a sulfhydryl  
4   group.

1           55.    The resin blend of any of claims 35-53 wherein said secondary  
2   polymerizable groups comprise electron deficient alkenes.

1           56.    The resin blend of claim 55 wherein said electron deficient alkenes  
2   independently are selected from the group consisting of substituted and unsubstituted  
3   alkenyl ester groups comprising a polymerizable unsaturated carbon-carbon bond,  
4   wherein said alkenyl group has from about 2 to about 12 carbon atoms.



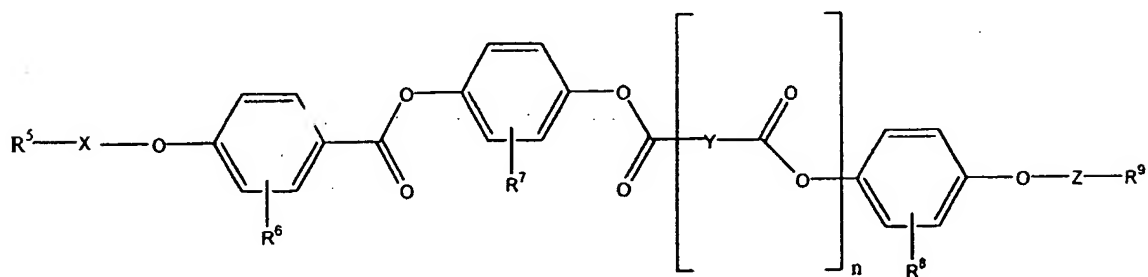
1           57.    The resin blend of any of claims 35-53 wherein said secondary  
2 polymerizable groups are selected from the group consisting of acryloyl groups and  
3 methacryloyl groups.

1           58.    The resin blend of any of claims 35-57 wherein X, Y and Z  
2 independently comprises from about 2 to about 10 carbon atoms.

1           59.    The resin blend of any of claims 35-57 wherein X, Y, and Z  
2 independently comprises from about 2 to about 6 carbon atoms.

1           60.    The resin blend of any of claims 35-57 wherein X, Y, and Z have 6  
2 carbon atoms.

1           61.    A composition having the following general structure:



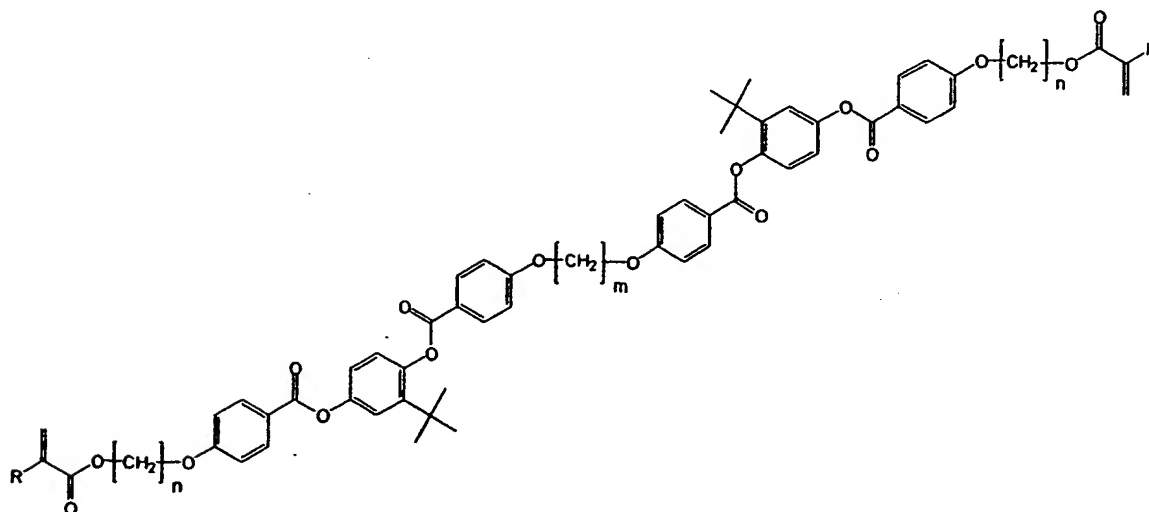
2    wherein

3    n is selected from the group of 0 and 1;

4    X and Y independently are selected from the group consisting of linear and branched  
5    alkyl groups having from about 2 to about 12 carbon atoms;

6    Z is selected from the group consisting of linear and branched alkyl groups having  
7    from about 2 to about 12 carbon atoms; provided that, when n is 0, Z is  
8    further selected from the group consisting of 2-alkyl-1,4-bis[-4-(alkyl-6-yl-1-  
9    oxo)-benzoyloxy]-benzene and, when n is 1, Z is further selected from the

- 10 group consisting of 4-oxoalkyl-benzoyl groups, wherein said alkyl groups  
 11 independently have from about 2 to about 12 carbon atoms;  
 12  $R^7$  is a bulky organic group having a bulk greater than  $R_1$  and  $R_3$ , said bulk being  
 13 adapted to provide sufficient steric hindrance for said liquid crystal monomer  
 14 to achieve a nematic state at room temperature while suppressing  
 15 crystallization of said blend at 20 °C;  
 16  $R^6$  and  $R^8$  are selected from the group consisting of hydrogen atoms and methyl  
 17 groups;  
 18  $R^5$  and  $R^9$  are polymerizable groups selected from the group consisting of  
 19 nucleophiles and groups comprising an electron deficient alkene.
- 1 86. A composition having the following general structure:

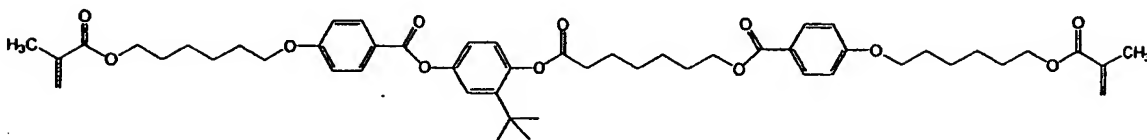


- 2 wherein  
 3  $R$  is selected from the group consisting of hydrogen and a methyl group; and  
 4  $n$  and  $m$  independently are selected from the group consisting of from about 2  
 5 to about 11.

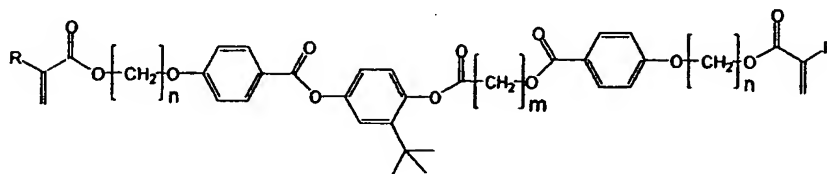


5 to about 12.

1 66. A composition having the following general structure:



1 67. A composition having the following general structure:



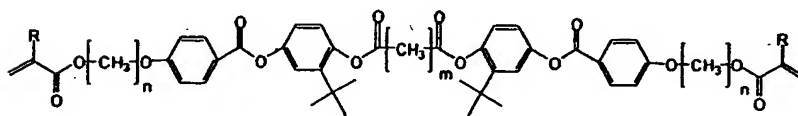
2 wherein

3 R is selected from the group consisting of H and CH<sub>3</sub>; and

4 n and m independently are selected from the group consisting of from about 2

5 to about 12.

1 68. A composition having the following general structure:



2 wherein

3 n and m independently are selected from the group consisting of from about 2

4 to about 12; and

5 R is selected from the group consisting of H and CH<sub>3</sub>.

1 69. The composition nonanedioic acid bis-(2- R<sup>7</sup>-4-{4-[6-(2-R-  
2 acryloyloxy)-alkyloxy]-benzoyloxy}-phenyl) ester wherein:

3 R is selected from the group consisting of H and CH<sub>3</sub>;

4           said alkyls have from about 2 to about 12 carbon atoms; and

5           R<sup>7</sup> is selected from the group consisting of a t-butyl group, a phenyl group, an  
6 isopropyl group, and a secondary butyl groups.

1           70.    The composition of any of claims 61-69 wherein R<sup>7</sup> is selected from  
2 the group consisting of t-butyl groups, phenyl groups, isopropyl groups, and  
3 secondary butyl groups.

1           71.    The composition of any of claims 61-69 wherein R<sup>7</sup> is selected from  
2 the group consisting of a t-butyl group and a phenyl group.

1           72.    The composition of any of claims 61-69 wherein R<sup>7</sup> is a t-butyl group.

1           73.    The composition of any of claims 61-72 wherein n and m  
2 independently are from about 2 to about 10, and said alkyl(s) of said secondary  
3 monomer independently have from about 2 to about 10 carbon atoms.

1           74.    The composition of any of claims 61-72 wherein said alkyl(s) of said  
2 secondary monomer independently have from about 2 to about 6 carbon atoms.

1           75.    The composition of any of claims 61-72 wherein said alkyl(s) of said  
2 secondary monomer have 6 carbon atoms.

1           76.    The composition of any of claims 61-75 wherein both of R<sup>5</sup> and R<sup>9</sup> are  
2 secondary polymerizable groups.

1           77.    The composition of any of claims 61-76 wherein said secondary  
2 polymerizable groups are nucleophiles selected from the group consisting of an ester  
3 group, an organic acid group, an amine group, a hydroxyl group, and a sulfhydryl  
4 group.

1           78.    The composition of any of claims 61-76 wherein said secondary  
2 polymerizable groups comprise electron deficient alkenes.

1           79.     The composition of claim 78 wherein said electron deficient alkenes  
2     independently are selected from the group consisting of substituted and unsubstituted  
3     alkenyl ester groups comprising a polymerizable unsaturated carbon-carbon bond,  
4     wherein said alkenyl group has from about 2 to about 12 carbon atoms.

1           80.     The composition of any of claims 61-76 wherein said secondary  
2     polymerizable groups are selected from the group consisting of acryloyl groups and  
3     methacryloyl groups.

1           81.     The composition of any of claims 61-80 wherein X, Y and Z  
2     independently comprises from about 2 to about 10 carbon atoms.

1           82.     The composition of any of claims 61-80 wherein X, Y, and Z  
2     independently comprises from about 2 to about 6 carbon atoms.

1           83.     The composition of any of claims 61-80 wherein X, Y, and Z have 6  
2     carbon atoms.

1           84.     A method for making a composition comprising  
2     providing a 4-hydroxyl benzoic acid comprising a carboxyl substituent;  
3     providing an alkylene group comprising an  $\alpha$ -halide group and an  $\omega$ -halide  
4     group;  
5     condensing said 4-hydroxyl of said benzoic acid with said  $\omega$ -halide group  
6     under first conditions effective to activate said carboxyl substituent and  
7     to produce a hydroxyl terminated alkyloxy comprising said  $\alpha$ -  
8     hydroxyl group at a first terminus and an activated carboxyl substituent  
9     of said 4-hydroxyl benzoic acid at a second terminus;  
10    providing a hydroquinone comprising a bulky organic group and comprising a  
11    first hydroxyl group para- to a second hydroxyl group, at least one of

12                   said first hydroxyl group and said second hydroxyl group being an  
13                   ionically activated hydroxyl group;  
14           condensing said activated carboxyl substituent with said at least one ionically  
15           activated hydroxyl group of said hydroquinone under second  
16           conditions effective to produce  $\alpha,\omega$ -bis-4-[4-{ $\omega$ -R- acryloxy-  
17           alkyloxy)-benzoyloxy}-2-R<sup>7</sup>- phenoxy carbonyl]-phenoxy-alkane.

1           85.    A method for making a composition comprising  
2           providing a 4-hydroxyl benzoic acid comprising a carboxyl substituent;  
3           providing an alkylene group comprising an  $\alpha$ -halide group and an  $\omega$ -halide  
4           group and comprising from about 2 to about 12 carbon atoms;  
5           condensing said 4-hydroxyl of said benzoic acid with said  $\omega$ -halide group  
6           under first conditions effective to activate said carboxyl substituent and  
7           to produce a hydroxyl terminated alkyloxy comprising said  $\alpha$ -  
8           hydroxyl group at a first terminus and an activated carboxyl substituent  
9           of said 4-hydroxyl benzoic acid at a second terminus;  
10          providing a 2-(R<sup>7</sup>)-4-[4-(6-acryloxy-alkyloxy)-benzoyloxy]-phenol  
11          comprising a bulky organic group and an ionically activated hydroxyl  
12          group para- to said [4-(6-acryloxy-alkyloxy)-benzoyloxy] group;  
13          condensing said activated carboxyl substituent with said ionically activated  
14          hydroxyl group under second conditions effective to produce  
15          nonanedioic acid- $\alpha,\omega$ -bis-(2-R<sup>7</sup>)-4-[4-{ $\omega$ -(2-R-acryloyloxy)-  
16          alkyloxy}-benzoyloxy]-phenyl ester.

1           86.    A method for making a composition comprising  
2           providing a 4-hydroxyl benzoic acid comprising a carboxyl substituent;

3 providing an alkanoyl halide comprising an  $\omega$ -halide group and having from  
4 about 2 to about 12 carbon atoms;  
5 condensing said 4-hydroxyl of said benzoic acid with said  $\omega$ -halide group  
6 under first conditions effective to activate said carboxyl substituent and  
7 to produce 4-( $\omega$ -R-acryloxy-alkyloxy) benzoic acid comprising an  
8 activated carboxyl substituent;  
9 providing a hydroquinone comprising a bulky organic group and comprising a  
10 first hydroxyl group para- to a second hydroxyl group, at least one of  
11 said first hydroxyl group and said second hydroxyl group being an  
12 ionically activated hydroxyl group;  
13 condensing said activated carboxyl substituent of said 4-( $\omega$ -R-acryloxy-  
14 alkyloxy) benzoic acid with said at least one ionically activated  
15 hydroxyl group of said hydroquinone under second conditions  
16 effective to produce 2-(R<sup>7</sup>)-1-[4-( $\omega$ -R-acryloxy-alkyl- $\alpha$ -oxy)-  
17 benzoyloxy], 4-( $\omega$ -halo- $\alpha$ -alkanoyloxy)-benzene.

1 87. The method of any of claims 84-86 wherein said bulky organic group  
2 is selected from the group consisting of t-butyl groups, phenyl groups, isopropyl  
3 groups, and secondary butyl groups.

1 88. The method of any of claims 84-86 wherein said bulky organic group  
2 is selected from the group consisting of t-butyl groups and phenyl groups.

1 89. The method of any of claims 84-86 wherein said bulky organic group  
2 is a t-butyl group.

1 90. The method of any of claims 84-89 wherein said alkyl has from about  
2 2 to about 6 carbon atoms.



1           91.     The method of any of claims 84-89 wherein said alkyl is hexyl.

1           92.     The method of any of claim 86-91 wherein said alkanoyl halide  
2 comprises from about 2 to about 10 carbon atoms.

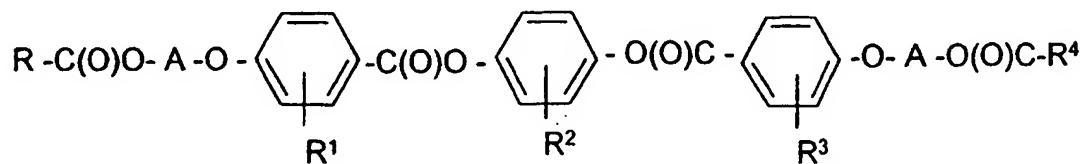
1           93.     The method of any of claims 86-91 wherein said alkanoyl halide  
2 comprises from about 2 to about 6 carbon atoms.

1           94.     The method of any of claims 86-91 wherein said alkanoyl halide has 6  
2 carbon atoms.

1           95.     The method of any of claims 84-94 wherein said  $\omega$ -halide group is  
2 chlorine.

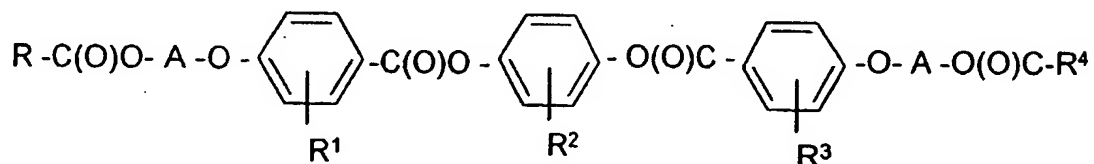
1           96.     The method of any of claims 86-95 wherein  
2 said first conditions comprise the presence of an acid halogenating agent; and,  
3 said second conditions comprise the presence of an ionic activating agent for  
4 at least one of said first and said second hydroxyl groups.

1           97.     A resin blend comprising a liquid crystal monomer at a 3:2 ratio to a  
2 secondary monomer said secondary monomer being 2-(t-butyl),1-[4-(6-acryloxy-  
3 hexyl-1-oxy)-benzoyloxy], 4-[4-{6-(3-acryl oxy-propionoxy)-hexyl-1-oxy}-  
4 benzoyloxy]-benzene, said liquid crystal monomer having the following general  
5 structure:



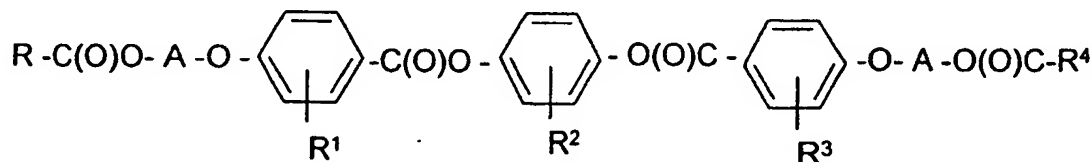
6     wherein  $R^2$  is a t-butyl group;  $R^1$  and  $R^3$  are hydrogen atoms; A is 6; and R and  $R^4$  are  
7 methacryl groups.

- 1            98.     A resin blend comprising an inorganic filler and a liquid crystal  
 2 monomer at a ratio of 3:2 to a secondary monomer said secondary monomer being 2-  
 3 (t-butyl),1-[4-(6-acryloxy-hexyl-1-oxy)-benzoyloxy], 4-[4-{6-(3-acryl oxy-  
 4 propionoxy)-hexyl-1-oxy}-benzoyloxy]-benzene, said liquid crystal monomer having  
 5 the following general structure:



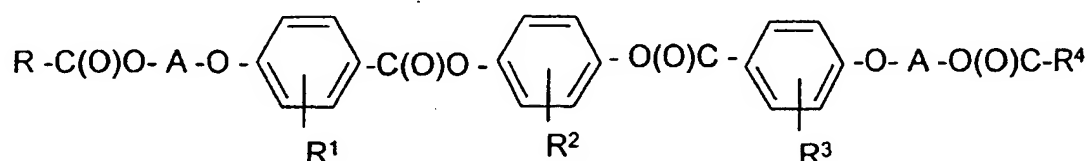
- 6 wherein  $R^2$  is a t-butyl group;  $R^1$  and  $R^3$  are hydrogen atoms; A is 6; and R and  $R^4$  are  
 7 methacryl groups.

- 1            99.     A resin blend comprising an inorganic filler and a liquid crystal  
 2 monomer at a 3:2 ratio to a secondary monomer, said secondary monomer being 2-(t-  
 3 butyl),1-[4-(6-acryloxy-hexyl-1-oxy)-benzoyloxy], 4-[4-{6-(3-acryl oxy-propionoxy)-  
 4 hexyl-1-oxy}-benzoyloxy]-benzene, said liquid crystal monomer having the  
 5 following general structure:



- 6 wherein  $R^2$  is a t-butyl group;  $R^1$  and  $R^3$  are hydrogen atoms; A is 6; and R and  $R^4$  are  
 7 methacryl groups.

- 1           100. A resin blend comprising an inorganic filler and a liquid crystal  
 2 monomer at a ratio of 3:2 to a secondary monomer, said secondary monomer being 2-  
 3 (t-butyl),1-[4-(6-acryloxy-hexyl-1-oxy)-benzoyloxy], 4-[4-{6-(3-acryl oxy-  
 4 propionoxy)-hexyl-1-oxy}-benzoyloxy]-benzene, and said liquid crystal monomer  
 5 has the following general structure:

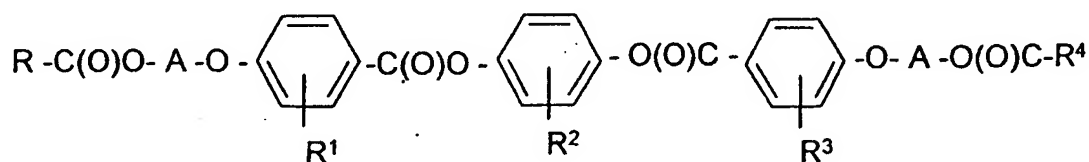


- 6           wherein  $R^2$  is a t-butyl group;  $R^1$  and  $R^3$  are hydrogen atoms; A is 6; and R  
 7           and  $R^4$  are methacryl groups.

- 1           101. A resin blend comprising an inorganic filler and a liquid crystal  
 2 monomer at a ratio to a secondary monomer, said secondary monomer and said ratio  
 3 being adapted to produce a nematic to isotropic transition temperature for said resin  
 4 blend of about 50 °C. or more.

- 1           102. The blend of claim 101 wherein said nematic to isotropic transition  
 2 temperature for said blend is about 60 °C. or more.

- 1           103. The blend of any of claims 101-102 wherein said liquid crystal  
 2 monomer has the following general structure:



- 3           wherein:

4      $R^2$  is a bulky organic group having a bulk greater than  $R_1$  and  $R_3$ , said bulk being  
5             adapted to provide sufficient steric hindrance for said liquid crystal monomer  
6             to achieve a nematic state at room temperature while suppressing  
7             crystallization of said liquid crystal monomers at 20°C;

8      $R^1$  and  $R^3$  are selected from the group consisting of hydrogen atoms and methyl  
9             groups;

10    A is selected from the group consisting of branched and linear alkyl groups having  
11             from about 2 to about 12 carbon atoms, wherein said branched alkyl groups  
12             comprise branches having from about 1 to about 4 carbon atoms; and

13    R and  $R^4$  are polymerizable groups, including but not necessarily limited to  
14             nucleophiles and electron deficient alkenes.

1             104. The blend of claim 103 wherein said polymerizable groups are acryloyl  
2             groups and methacryloyl groups.

1             105. The blend of claim 103 wherein  $R^2$  is a t-butyl group.

1             106. The blend of any of claims 101-103 wherein A comprises from about 2  
2             to about 6 carbon atoms.

1             107. The blend of claim 101-103 wherein A has 6 carbon atoms.

1             108. The resin blend of any of claims 18-60 or 97-107 comprising a dental  
2             restorative material.

1             109. The resin blend of any of claims 18-60 or 97-107 comprising a  
2             precursor to an optical device.

1             110. The resin blend of any of claims 18-60 or 97-107 comprising an  
2             adhesive.

1           111. Optical devices comprising a composite formed using the resin blend  
2 of any of claims 18-60 or 97-107.

1           112. A composition for making optical devices comprising the resin blend  
2 of any of claims 18-60 or 97-107.

1           113. A bone restoration comprising a composite formed from the resin  
2 blend of any of claims 18-60 or 97-107.

1           114. A dental restoration comprising a composite formed from the resin  
2 blend of any of claims 18-60 or 97-107.

1           115. A method for delaying crystallization of a primary liquid crystal  
2 monomer which otherwise crystallizes in under 30 minutes after addition of inorganic  
3 filler at a temperature of 20 °C, said method comprising providing a resin blend  
4 comprising said primary liquid crystal monomer and at least one secondary monomer,  
5 whereby upon addition of said inorganic filler to said resin blend at a temperature of  
6 20 °C, said resin blend maintains a nematic liquid crystallin state for about 30 minutes  
7 or more and exhibits about 4 vol. % or less polymerization shrinkage.



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*For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.*

(54) Title: ULTRA-LOW SHRINKAGE COMPOSITE RESINS BASED ON BLENDED NEMATIC LIQUID CRYSTAL MONOMERS

(57) Abstract: A novel method of making liquid crystal monomers, novel monomer blends, and novel secondary monomers for use

WO 02/070543 A3

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/07143

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : C07C 69/76

US CL : 560/066, 73

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 560/066, 73

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
STN CAS file registry STRUCTURE

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 869 112 A1 (DAIMLER-BENZ AKTIENGESELLSCHAFT) 17 MARCH 1998 page 18, figure 4, reaction (1) page 22, figure 8b.	1-4, 84, 85 18-22, 61-70
X	EP 0 242 278 A2 (BOARD OF TRUSTEES OF THE UNIVERSITY OF ILLINOIS) 21 OCTOBER 1987 entire reference especially page 7.	97-105, 115



Further documents are listed in the continuation of Box C.



See patent family annex.

\* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T"

later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X"

document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y"

document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&amp;"

document member of the same patent family

Date of the actual completion of the international search

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# INTERNATIONAL SEARCH REPORT

International application No.

PCT/US02/07143

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claim Nos.: 86-96  
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:  
There are two different claims numbered 86, and one cannot tell which of the two the dependent claims depend thereon
3. ☒ Claim Nos.: 5-17, 23-60, 71-83, 87-96, 106-114  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐  
☐

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

